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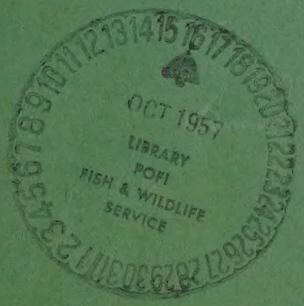

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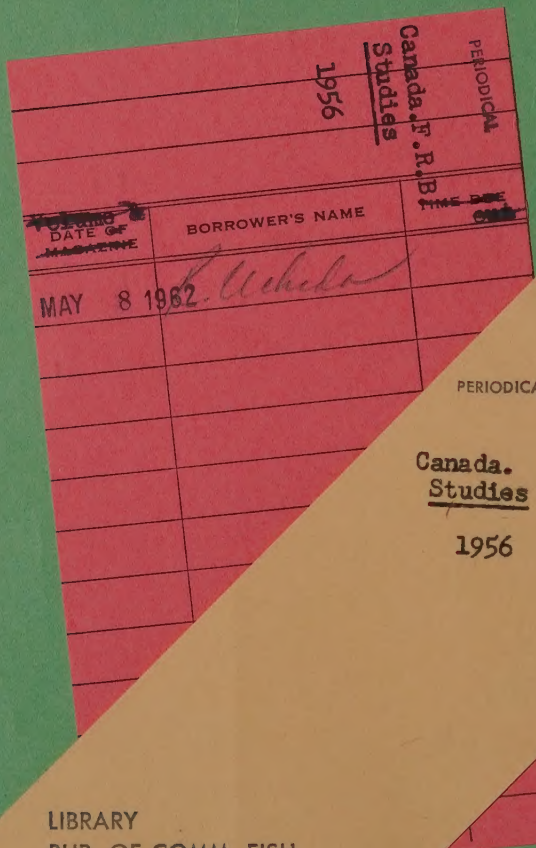

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NORTHERN FUR SEAL IN THE INSIDE COASTAL WATERS OF BRITISH COLUMBIA

BY J. I. MANZER AND I. MCT. COWAN

As far as it can be determined from the literature dealing with migration and distribution of the species, only four northern fur seals (*Callorhinus ursinus*) have been reported from inside coastal waters of British Columbia. Three tagged seals, age six to ten months, were found dead on the beaches near Vancouver (Kenyon and Wilke, 1953); a fourth seal, a white-whiskered cow, was observed in the same area during April, 1950 (Anon., 1954). During the past few years, however, several reports have been received, some of them made as early as the nineteen-thirties, which provide additional evidence that seals enter inside waters. It seems appropriate to report these occurrences and thus add to what is already known about the migratory habits of the species. The paper also affords the opportunity to make available measurement data of two yearling seals examined in January, a month when members of this age-group are extremely difficult to obtain.

Acknowledgments.—A number of individuals have contributed observations presented in this paper. In particular, special thanks are due M. E. Lohbrunner, former pelagic sealer and retired licensed fur-buyer; J. Stokes and W. Winsby of the Department of Fisheries of Canada, biologist and inspector, respectively; G. Johnson and R. Kelly, fishermen; and R. S. Hayes, Game Warden.

Methods.—The paper is based on authentic sight records of 65 + fur seals and examination of another 13 dead or dying individuals washed up on the beaches or accidentally killed. The method of measuring total length, hind flipper length, condylobasal length and mastoid width was similar to that described by Scheffer and Wilke (1953). The total length was measured to the nearest half-centimeter; and the other variates to the nearest millimeter. The weights are live weights recorded to the nearest half-pound and converted to the nearest one-tenth kilogram.

Occurrence of fur seals.—Table 1 shows in chronological order the observations of fur seals in inside coastal waters of British Columbia. Individuals were sighted between Tuck Inlet, in the north, and the Fraser River and eastern end of Juan de Fuca Strait, in the south. In waters north of Queen Charlotte Sound, seals were seen during the early part of 1954 in larger passages and inlets. The largest concentration, "about two dozen" individuals, was reported off Butedale, located in Fraser Reach. In all probability seals have been observed in northern waters before, but not reported. In southern waters, seals were seen in the northern and southern approaches to the Strait of Georgia as well as in the Strait. In the Strait of Georgia, fur seals were seen in several years but always in approximately the same areas, the upper and lower ends. In January 1955 about 20 were reported in waters adjacent to Cape Mudge and in Sutil Channel. None has been reported from between the latitudes of Cape Lazo and Burrard Inlet, even though boat traffic through these waters is heavy.

Except in two instances, only solitary seals were seen. This tendency for

TABLE 1.—*Records of northern fur seals in inside coastal waters of British Columbia*

Year	Month	Number	Location	Remarks
About 1930	July	1	Between Cape Lazo and Cape Mudge	
About 1937	June	1	Off Sooke	Taken by Indian hunters.
		1	Off Race Rocks	Shot. Mistaken for hair seal.
1939	July	1	Goose Islands	Yearling. Female.
1946	Nov.	1	Kye Bay, East coast of Vancouver Island	Juvenile. Sex unknown. Skin deposited in Museum of Zoology, U. B. C.
1947	?	1	Between Ten-mile Pt. and San Juan Islands	White-whiskered female.
1948	Jan.	2	Fraser River near Steveston	Yearlings. One, a female, taken alive. Skeleton deposited in U. B. C.
1950	?	1	Cortes Island	Carcass washed ashore.
1952	Jan.	1	Sutil Ch., 2 mi. south of Stuart Island	
	Feb.	1	Broughton St., 1 mi. N.E. of Beaver Cove	Shot. Mistaken for hair seal. Small female.
		1	Knight Inlet near Protection Pt.	Shot. Mistaken for hair seal. Small female.
		1	Blackfish Sd.	
1953	Aug.–Sept.	1	Between Green Sea Bay, Discovery Passage, and Cape Mudge.	Six different reports of a small seal in this area. In all probability reports concerned same individual.
	Sept.	1	Sargeaunt Pass	Travelling south.
1954	Jan.	5	Tuck Inlet	Yearlings. Four dead. A fifth, a male, captured for display in Zoo. Died.
		1	Port Edward	Yearling. Washed ashore Dead.
		1	Outside Prince Rupert Harbour	Yearling. Washed ashore Dead.
		1	Pitt Pt. in Grenville Ch.	"Small-sized".
	Feb.	1	Bella Bella	Yearling.
	Feb.	1	Fitzhugh Sd.	Yearling.
		1	Beaver Cove	
		1	Prince Rupert Harbour	Yearling.
	Mar.	1	Cramer Passage	
		"About 2 doz."	Butedale	Small size and observed individually.
1955	Jan.	About 20	Near Cape Mudge and in Sutil Ch.	2 killed. Size not reported.

seals to be found singly while at sea appears to be the rule rather than the exception, and has been observed by Wilke (1951) and other fur seal biologists (Anon., 1954) when conducting pelagic research in the North Pacific Ocean.

The number of seals reported in any one year, with the exception of 1954 and 1955, has never exceeded four. In 1954 between January and March at least 35 were seen, all but one in northern waters. That the incidence of seals in British Columbia waters was generally greater in that year was also expressed by Canadian Department of Fisheries personnel when comparing the number of seals seen in 1954 with that in other years. Size reports and carcasses found on the beaches indicate that these seals belonged to the pup-class of the preceding summer. On the basis of ten tags recovered from dead seals from Oregon to Alaska, this year-class is known to have been subject to high mortality that resulted from storm action (Kenyon and Wilke, 1954). Scheffer (1950) reports unusual numbers of seal carcasses along the coasts of Washington and Oregon during January and February, 1950, subsequent to a long series of storms. Meteorological data for the northern part of the province show that during the winter of 1953–54 the frequency of winds of gale force was above average, and it seems likely, therefore, that seals reported from the British Columbia coast in winter represent storm-weakened animals that had found shelter among the coastal islands.

Seals were seen in all months but April, May, October and December (Table

TABLE 2.—*Seasonal occurrence of northern fur seals in inside coastal waters of British Columbia*

Month	Number	Location	Remarks
Jan.	31	Fraser River, Tuck Inlet, Pitt Pt., near Cape Mudge and in Sutil Ch.	Excluding one "small-sized" individual off Pitt Pt. and seals seen near Cape Mudge and in Sutil Ch., all animals were yearlings.
Feb.	6	Beaver Cove, Knight In., Blackfish Sd., Bella Bella, Fitzhugh Sd.	2 were small females.
Mar.	1 + "about 2 doz."	Cramer Passage, Butedale	Seals off Butedale were small sized.
April	nil		
May	nil		
June	2	Race Rocks, Sooke	
July	2	Between Cape Lazo and Cape Mudge, Goose Is.	One, a yearling female.
Aug.-Sept.	2	Between Green Sea Bay and Cape Mudge, Sargeaunt Passage	One, a yearling.
Oct.	nil		
Nov.	1	Kye Bay	Juvenile.
Dec.	nil		
Unknown	2	Between Ten-mile Pt. and San Juan Is., Cortes Is.	One, a mature female.

2). Excluding 1954 data, most were seen during January and February. One July taken specimen was a yearling in excellent condition and was probably merely an animal that had not migrated with most members of that age group; other summer records can be explained similarly. The winter occurrences coincide with the southward movement of the seals from their northern breeding colonies.

Measurement data for two yearlings, a female collected January, 1948 in Fraser River and a male collected January, 1954, in Tuck Inlet, follow: Weight, F. 7.3 kg.—M. 7.9 kg.; total length, F. 72.5 cm.—M. 73.0 cm.; hind flipper to heel length, F. 240 mm.—M. 265 mm.; condylobasal length F. 144 mm.—M. 149 mm.; mastoid width, F. 88 mm.—M. 89 mm. Comparing these data with those given by Scheffer and Wilke (1953) for the pup and yearling age-groups examined on the Pribilof Islands, it was found that our animals fall into the first year age-group, except that the male is, in total length, undersized; indeed it falls into the length category of newborn. The female, on the other hand, has a mastoid width greater than that of a 1¼ year animal.

Discussion.—The occurrence of fur seals in inside coastal waters of British Columbia appears to be rare and limited mainly to immature individuals. Within the past decade, however, they have been observed more frequently. This may be due partly to better recognition of fur seals by fishermen and other mariners.

Three factors can be responsible for the occurrence of seals in inshore waters along the British Columbia coast: increased vagrants from a herd of maximal size; aberrant or unusual migratory behaviour leaving animals in southern waters during the summer; and storm driven waifs finding shelter during the mid-winter period. There is also the possibility of changed distribution of the younger age-groups in the wintering herd. Future observations of fur seal occurrence correlated with weather conditions will help to elucidate these possibilities.

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Pacific Biological Station, Nanaimo, B. C. and Department of Zoology, University of British Columbia, Vancouver, B. C. *Received March 27, 1955.*

Necessary equipment for the freezing of fish

Équipement nécessaire pour la congélation du poisson.

W. A. MacCALLUM*

Atlantic Fisheries Experimental Station, Halifax, Nova Scotia (Canada).

SOMMAIRE

1° *Systèmes à compression : certains aspects techniques de la tendance actuelle vers des systèmes à plusieurs étages et des basses températures appliquées dans les installations typiques en Amérique du Nord et en Europe.*

2° *Systèmes à absorption : essais effectués au Canada et ailleurs et conclusions tirées de l'application des systèmes à absorption à bord des navires sur les côtes occidentale et orientale des Etats-Unis.*

Possibilités économiques de l'emploi de grandes machines à absorption pour les installations terrestres à Terre-Neuve.

3° *Eléments basse pression pour la congélation rapide à terre et en mer : emploi de la recirculation du liquide et de l'alimentation par gravité et leur effet sur le rendement de la transmission de chaleur ; simplicité de la régulation et de l'entretien.*

Congélation en tunnel, congélation en saumure.

4° *Utilisation du froid et problèmes connexes dans l'industrie des « tablettes » de poisson (fish sticks).*

5° *Besoins en matériel de congélation dans l'industrie du poisson frais.*

Recent research and development suggest a discussion of refrigeration equipment for the trade in fresh and frozen fish which emphasizes the following topics:—

1. The development of methods for chilling other than through the use of ice, and for freezing, in an attempt to improve upon the quality of fish handled in ice.
2. Investigations concerning the suitability of use of ammonia-water absorption systems for the freezing of fish.
3. Characteristics of operation of certain equipment now in commercial use.

PART I

Projects of the first category vary in type and emphasis in as much as the type of fishery in their respective locations varies.

* Research and Development Engineer.

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The considerations and historical treatment of freezing at sea were reported in 1951 [39] and are recommended as background material.

In the practical application of freezing at sea (early investigations by H. C. Godsil (26, 27, 28), the Pacific Tuna Clipper employing refrigerated brine wells for chilling and freezing the fish and for subsequent dry storage, remains in the fore. On the large scale operations in which they are used, ammonia compression systems powered by large diesel generating sets give dependable service [23]. The techniques practised do not permit the rapid freezing required for the handling of volume catches of other fish, e.g. Northwest Atlantic groundfish. The principal contribution of the California development to other branches of fishing affects mainly the design, location and use of primary refrigeration and ancillary equipment.

Small Freon-12 refrigeration compressors operating aboard ship at positive suction pressures, may prove adequate in conjunction with appropriate evaporator surfaces for chilling sea water and brine used for cooling and freezing premium catches, e.g., shrimp [21,36,47], salmon [2, 32], and halibut. Studies concerning the possibility of the use of eutectic ice, frozen in this manner, to provide a reserve of refrigeration for freezing, are in progress [32].

The major investigation into the freezing of ungutted groundfish in brine aboard the trawler *Delaware*, and into the use of this product for frozen fillet production ashore, is continuing [33, 43, 18, 19, 44, 48, 3, 45, 49, 34, 35]. Features of this work are:—

1. The application of a technically practical freezing device.

2. The use of moderate refrigerant suction pressure [brine at — 17.7° C to — 15° C (0° F to 5° F)].

3. Coupling of operations at sea with those ashore to produce a product suitable for the frozen fish trade.

The efficiency and economy of such a freezing operation might be high if provision were made on trawlers for installation of all refrigeration producing equipment in space other than the fish room.

The use of sugar in calcium chloride brine permits lower freezing temperatures than are possible with sodium chloride. The sugar eliminates salt penetration [35] but is too expensive for use on trawlers [50].

Sugar is being used in sodium chloride brine with reported success by one organization engaged in the shrimp trade [47].

Torry Research Station has reported on vertical plate freezers for use aboard ship [57, 25, 17]. Vertical plates are simpler to operate than horizontal ones for the freezing of whole groundfish. Effective thermal contact between plates and fish was found possible without using water to fill voids. Slabs 11.4 cm (4 1/2 inches) thick were quick frozen at evaporation temperatures of about — 35° C (— 30° F). The refrigerant was Freon-12. Future work is concerned with adaptation of this type of equipment to the trawler.

A rapid blast freezer has been developed for freezing Rock Lobster tails [22]. Containers are stacked in trolleys at an angle to permit low temperature forced air to disrupt the stagnant air film next the package surfaces. Freezing time is 6 to 8 hours compared with 20 to 24 hours in pipe-rack freezers [52].

Work is continuing on handling techniques and packaging methods for quick, partial freezing of fish fillets in wholesale packets [42]. The object is to ensure immediate cooling after packaging, rather than to depend upon cooling by ice during shipment. *Fig.* 1 illustrates typical cooling curves for fillets located at specified perpendicular distances from the large flat surfaces of the metal containers. After about 30 minutes in a blast freezer, the containers are stored at 0°C (32° F). Two and one-half hours later the temperatures of all fillets have equalized.

Aboard the factory ship *Fairtry* and in shore plants in Newfoundland, suitable types of groundfish are being filleted by machine pre rigor and during rigor [31, 46].

Continued success with mechanical equipment should promote the growth of the frozen fish trade when fish are plentiful and labour is unavailable or costly.

Resourcefulness has been shown in the design of plate freezers for *Fairtry* to meet structural and space requirements for handling packaged fish at sea [1]. A secondary refrigerant, calcium chloride, is used in the freezers.

Processes to satisfy the needs of the fish stick industry are being developed within

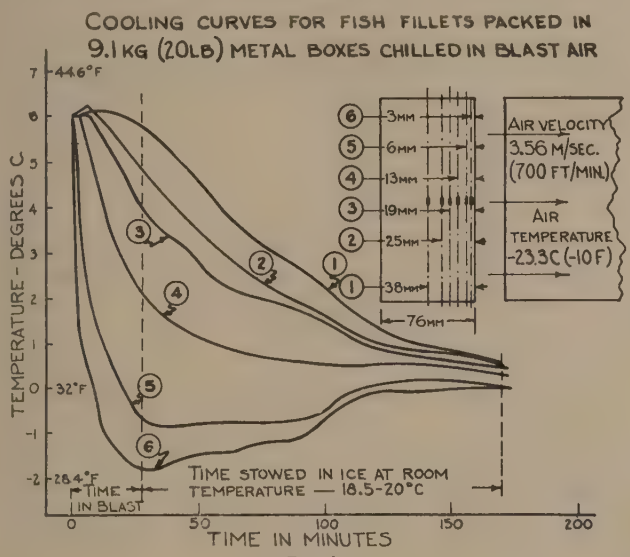

FIG. 1.

that industry [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 58]. No detailed results of research work in this field are being released.

Plate freezers are used for freezing the original blocks. More refrigeration capacity is required for cooling and freezing the sticks after frying than for block freezing. Individual sticks may be cooled in ambient air, then cooled in recirculated refrigerated air, then packaged and frozen in blast freezers. Both single and two stage ammonia compression systems are in use.

PART II

Specific information on the operating characteristics of two small ammonia-water absorption machines has been obtained as the result of test work [29, 30] with a 2-ton single stage unit and the use of a 20-ton single stage machine on the *Delaware* [18, 48]. The two machines are of the same general design.

The 2-ton unit utilizes a sieve plate rectifying column mounted over a shell and tube steam heated generator. The reflux ratio was fixed at 0.68. The design was for 99.97 per cent ammonia to the condenser. The rate of strong aqua circulation was fixed at about 0.2 l/sec (3 U.S. gal./min.). The machine was tested for cooling water temperatures from 3.3° C to 26.6° C (38° to 80° F), steam pressures from 0.70 kg/cm² to 2.8 kg/cm² (10 to 40 p.s.i.g.) and evaporator air temperatures from 0° C to — 28.9° C (32° F to — 20° F). The tests of capacity and efficiency showed the

machine to be responsive to changes in heat added and removed, in the manner expected. Performance factors varied between 0.35 and 0.45. Compared with the performance of European systems the values are low. Such machines compare favourably in operating cost with compressors only where boiler fuel costs are low and exhaust steam is available. The investigation emphasized the need for automatic controls to ensure maximum ease and efficiency of operation.

The latter point is stressed also as a result of operation of the 20-ton plant on the *Delaware*. The recent installation of several controls is expected to increase stability of operations materially [51].

Large ammonia-water absorption installations in North America tend towards maintenance of a steady state in the rectifier-generating system regardless of load. The investigations referred to above indicate a need for such control in the smaller machines as well. The cost of controls will be an important consideration in determining the lower limit to the size of machines which could compete successfully with the compression system in the freezing of fish.

Present investigations which may lead to the establishment of fish freezing plants at carefully selected sites in Newfoundland, point out the possibilities in the design of relatively large balanced operations employing ammonia absorption equipment, in localities where a source of low cost electric power is unavailable [24, 56, 55, 20, 37]. For a typical large, frozen fish, fish meal and liver operation, a good heat balance may be obtained when electrical requirements, provided by a back pressure steam turbo-generator, are kept to a minimum, and all heat requirements including those for absorption refrigeration, are provided by rejected steam. One analysis shows the ratios of energy requirements chargeable to these operations over the energy requirements for necessary electric power, to be as follows: freezing fillets: 1.0751; holding facilities: 0.645; ice manufacture: 1.370; fish meal: 3.000; liver oil: 0.123; heating: 2.560. Total: 8.773. The calculations assume 100 per cent utilization of equipment and that electric power for refrigeration is confined to the operation of the aqua pump motor and the cooling water pump motor. The total of the ratios may be increased substantially where the opportunity exists to obtain fresh cooling water and natural head eliminates the need for power for pumping.

The ratio of cost of diesel oil to Bunker C grade petroleum fuel in this area is about 2.64, hence the use of the heavy petroleum fuel makes the cost of steam for processing work only 38 per cent of that when diesel fuel is used.

Costs of electricity generated with this fuel are less than one fifth of those when diesel electric generators are used.

Large supplies of cool water for condensers and absorbers suggest the possibility of a performance factor of about 0.44 for an absorption refrigeration plant suited to this application. Energy consumption per ton of refrigeration is lower for a single stage compression system but high fuel costs for diesel operation contribute to an unfavourable cost picture for this system.

Other points in favour of the absorption system in this application are 1° low first costs of the primary refrigeration plant installed, 2° low first costs of housing the primary refrigeration plant, and 3° maintenance and replacement costs of equipment.

PART III

An excellent review of certain general considerations in the design of fish freezing plants is available [40].

Need for the highest design and maintenance standards in the operation of gravity fed flooded plate freezers has been reported [53]. Refrigeration efficiency was found to be extremely low in some plates. Such plates were usually midway between the top and bottom (Table I), although it was not uncommon to find the top plate without refrigerant. Using the same standard of measurement, the fastest freezing

recorded throughout all stations of any freezer when operating efficiency was maximum, was 40 minutes. However, a slight gradient to plates or obstructions caused by metal fittings prevent positive purging, and repeated inefficiencies are experienced. Investigation of freezer performances is being continued. Certain freezers may be tested under forced circulation of ammonia to provide comparative data.

TABLE I.

Temperatures (°C) in the Centre of 35 mm (1 3/8 inches) Slabs of Fish Fillets in Metal Trays in a Poorly Functioning Gravity Fed Flooded Plate Freezer. (Pressure in suction line for ammonia refrigerant at freezer — 50 to 75 mm/Hg/vacuum).

Time in Freezer (Minutes)	5	10	15	30	50	65	80
Freezer Station Number							
1	6.4	0.3	— 1.4	— 4.7	— 15.4	— 25.7	— 28.9
2	4.2	1.0	— 1.4	— 2.8	— 8.9	— 16.7	— 27.5
3	2.6	— 0.6	— 1.4	— 5.5	— 21.4	— 27.5	— 28.9
4	2.6	0.1	— 1.3	— 2.7	— 7.8	— 19.1	— 26.3
5	5.9	2.0	— 0.3	— 2.1	— 4.4	— 7.2	— 20.9
6	3.0	0.0	— 1.1	— 2.1	— 2.1	— 3.5	— 11.6
7	4.8	1.4	— 0.4	— 2.1	— 2.1	— 4.2	— 22.2
8	2.7	— 0.1	— 1.7	— 2.1	— 4.4	— 12.2	— 25.0
9	3.7	0.4	— 1.1	— 2.7	— 3.6	— 16.6	— 28.9
10	— 2.2	— 2.7	— 2.4	— 13.0	— 28.9	— 28.9	— 28.9

Forced circulation systems have been installed in several moderately sized, established fish freezing plants in Canada's Maritime Provinces. Carry-over of liquid to suction lines during the period of peak heat transfer has been eliminated and fewer oil problems have been reported than for some gravity fed flooded systems. Freezing rates appear to be entirely satisfactory. In such existing composite freezing and holding establishments, forced circulation of ammonia and multistage compression can often improve plant economy. Evaporators in rooms and freezers may be forced circulated from one low pressure receiver often without alteration to existing evaporators. Valves for each evaporator may be set and practically no daily regulation is required. Forced circulation systems are in use in a number of new plants also.

A noteworthy point in the design of the flooded system for the large freezing plant is illustrated by the Bergen installation [41]. It is impossible for oil to contaminate the ammonia refrigerant, since the latter is condensed by the primary refrigerant, Freon-12.

A number of other factors affect the efficiency of operation of plate freezers [54, 38]. Pressure on the fish must be uniform, sufficient, but not excessive. Wood spacers are widely used, sometimes with excellent results. Warping of the spacers can result in poor contact of packaged fish with the plates. Metal spacers are considered more reliable.

Some operators have experienced little success with hot gas defrosting despite modern light-weight plate design. Careless or indifferent attention may result in bulged plates, split hoses and injury or loss of life. Warm water and steam are widely used for defrosting. A more suitable design for the floor of freezing cabinets to permit propre shedding of water from defrosting is considered essential. Purging of oil from the headers should be a complementary operation.

In the freezing of panned, unpackaged fillets, moisture and solid material may squeeze out and freeze on plates. Ridges may build up and result in lack of contact and uneven freezing rates. Sheets of metal placed over the plates eliminate this problem without making an appreciable difference to the rate of freezing.

CONCLUSIONS

The development of techniques for chilling and freezing fish, as an alternative to stowage in ice, is being pursued vigorously. For most operations, commercial proving is still necessary.

The role of the ammonia-water absorption machine in the fishing industry will be confined to situations where exhaust steam is available for refrigeration purposes and where boiler fuel costs are low. The cost of the control equipment necessary for proper operation will be a factor in determining the commercial lower limit to machine size.

Forced circulation of ammonia refrigerant is being used with satisfactory results in both old and new fish freezing plants. In the former, fewer problems in freezing have resulted than with gravity fed flooded freezers. The efficiency of plate freezers may be increased materially through careful operation and maintenance of equipment.

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THE CONSTITUENTS OF COD LIVER WITH VITAMIN B_{12} ACTIVITY FOR LACTOBACILLUS LEICHMANNII[1]

By Beryl Truscott and P. L. Hoogland

Abstract

The identity of the compounds that together form the total microbiological vitamin B_{12} activity of cod-liver residue was determined by a fractionation procedure involving ion exchange, countercurrent distribution, partition chromatography, and microbiological assay. The presence of cyanocobalamin, hydroxocobalamin, and the desoxyribosides of thymine, uracil, hypoxanthine, xanthine, and guanine was demonstrated. The total vitamin B_{12} activity, as determined by microbiological assay with *Lactobacillus leichmannii*, and its distribution in cod-liver residue, were very similar to those of beef liver. Cod-liver residues may be used to replace beef liver in vitamin B_{12} preparations.

A procedure has been developed in this laboratory (12) for the production of cod-liver residue which is relatively free of oil but contains large amounts of protein and B-vitamins (6, 11). The high vitamin B_{12} activity of the material seemed to make it particularly interesting to the pharmaceutical and feed manufacturing industries.

For a more complete evaluation of the nutritive properties of the residue, it was thought necessary to compare with data available for beef liver the "total vitamin B_{12} activity", as determined by microbiological assay, and the qualitative composition of the mixture of constituents that together form this total activity.

Experimental

1. *Raw Material*

The raw material used in this work was dried, defatted cod-liver residue (11).

2. *Equipment and Methods*

Ion Exchange

Columns of Amberlite IRA-400* in the hydroxyl form were used; they were operated under constant pressure. The eluant was 0.05 molar acetic acid.

Countercurrent Distribution

The 25-tube apparatus described by Craig and Post (2, 3) was used; the solvent system was isobutanol/water/acetic acid.

Partition Chromatography

Columns of purified potato starch (4) were used with *n*-butanol/water.

Paper chromatography was done on Whatman No. 1 paper strips. Various solvent systems were used: *n*-butanol/water, *n*-butanol/water/ammonia, *n*-butanol/water/ethyl acetate/morpholine, and aqueous disodium hydrogen phosphate/isoamyl alcohol. The positions of growth factors on the paper

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**The Rohm and Haas Company, Washington Square, Philadelphia.*

were determined by bio-autography according to Winsten and Figen (13); the medium was Difco-CS vitamin B_{12} agar, the organism *Lactobacillus leichmannii* (A.T.C.C. 4797).

Absorption Spectra

Ultraviolet absorption spectra were determined with the Beckman DU spectrophotometer; the instrument was equipped with standard 10 mm. cells, as well as with a microattachment* and an adapter for direct photometry of paper strip chromatograms (10).

Microbiological Assay of Vitamin B_{12} Activity

The procedure and medium described by Peeler *et al.* (9) were used.

3. Results

Five hundred grams of dried, defatted liver residue was extracted exhaustively with water; the extract concentrated *in vacuo* to 125 ml. Microbiological assay before and after treatment with alkali to destroy cobalamins showed that at least 75% of the total activity was due to these compounds and the remainder to alkali stable growth factors. The total vitamin B_{12} activity was 1.5 μgm. per gm. The concentrate was extracted with isobutanol, the solvent removed from the extract by vacuum distillation, and the residue taken up in 100 ml. of water. The extract was dark brown and had a solid content of 12.6%. It was shown by paper chromatography that the aqueous concentrate contained at least four and probably six growth factors with vitamin B_{12} activity, and that the non-vitamin B_{12} part had been extracted practically quantitatively by the isobutanol whereas the vitamin B_{12} remained in the aqueous layer. The isobutanolic extract contained at least three growth factors. The aqueous layer was subjected to chromatography on phosphate-treated paper (14) and the presence of cyanocobalamin (vitamin B_{12}) and hydroxocobalamin (vitamin B_{12a}) was demonstrated.

The extract obtained with isobutanol was purified by passage through a column of Amberlite IRA-400 and elution with 0.05 molar acetic acid. This treatment removed 59% of the solids but none of the vitamin B_{12} activity. The resulting solution was evaporated to dryness and the residue taken up in 25 ml. of "bottom solvent" (isobutanol/water/acetic acid). Portions of 8 ml. were then subjected to 25-stage countercurrent distribution. The contents of each tube were analyzed by paper chromatography (*n* butanol/water). The results are given in Fig. 1. It may be seen that the distribution had partially separated the growth factors. Further distribution was carried out with the combinations marked I, II, III, and IV in Fig. 1. The results were those of Fig. 2. The fractions were then combined into three groups: A, B, and C (Fig. 2) and the components of each separated by chromatography on starch columns. From A and B, three fractions were obtained and from C only two. Each of these was analyzed by paper chromatography using isoamyl alcohol/phosphate buffer. The results are given in Table I.

* *Pyrocell Manufacturing Company, 207 East 84th Street, New York.*

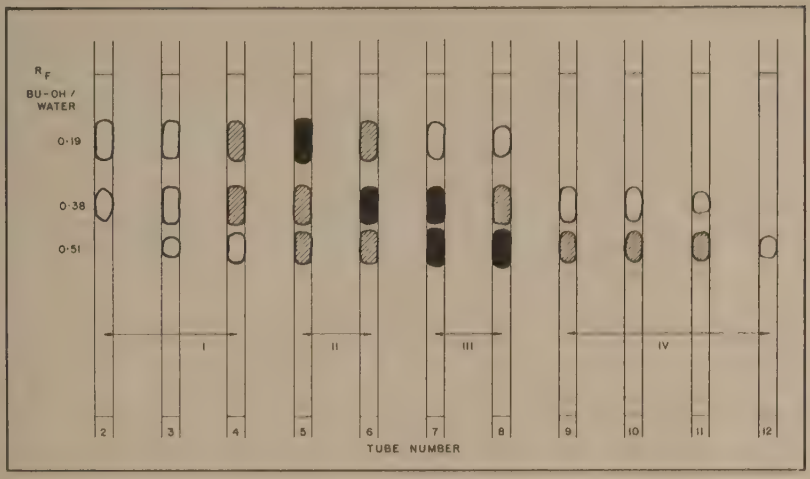

FIG. 1. Fractionation of growth factors by countercurrent distribution (isobutanol/acetic acid).

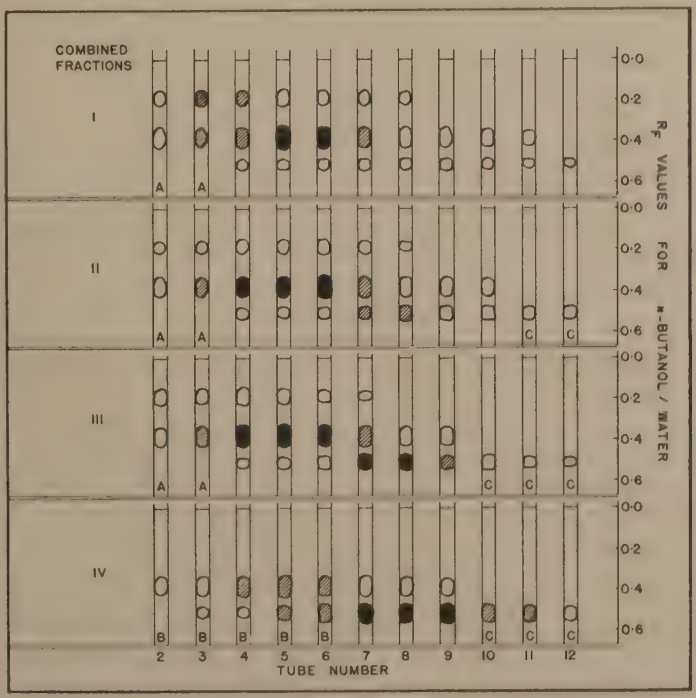

FIG. 2. Further fractionation by countercurrent distribution.

It is evident that the first component of fractions A and B was not homogeneous but contained at least two compounds; one single growth factor occurred in each of the others. The first component was separated into two parts by chromatography on paper sheets with *n* butanol ammonia. Each new part contained one factor with R_F 0.05 and 0.13 respectively.

TABLE I

SEPARATION OF COMPONENTS OF FRACTIONS A, B, AND C ON STARCH COLUMNS AND ANALYSIS OF THESE COMPONENTS BY PAPER CHROMATOGRAPHY

Fraction	R_F	
	Starch column with *n*-butanol/water	Paper strips with isoamyl alcohol/phosphate buffer
A	0.20*	0.58 to 0.66
	0.38	0.75
	0.51	0.71
B	0.20	0.59 to 0.66
	0.38*	0.74
	0.51	0.71
C	0.38	0.74
	0.51*	0.71

* *Most abundant component.*

Thus, four solutions had been obtained: I from fraction C (R_F *n*-butanol/water 0.51), II from fraction B (R_F 0.38), III from fraction A (R_F *n*-butanol ammonia 0.13), and IV from fraction A (R_F *n*-butanol/ammonia 0.05). The ultraviolet absorption spectra of these solutions were found to have the general appearance of spectra of derivatives of purines and pyrimidines. R_F values for the factors of the four solutions were determined with four different solvent systems. A number of purine and pyrimidine derivatives was tested for their ability to replace vitamin B_{12} as a growth factor for *Lactobacillus leichmanni*; only desoxyribosenucleosides showed strongly positive tests (see Table II). The desoxyribosenucleotides showed very slight ability to replace vitamin B_{12}. Two explanations are possible: (1) the nucleotides are weak growth factors themselves, or (2) these compounds become active only after conversion into the corresponding nucleosides. The latter was borne out by the change in activity of solutions of nucleotides upon standing: thymidylic acid in aqueous solution, stored at 2° C. for three weeks, increased its activity from practically zero to that of thymidine. It was demonstrated by paper chromatography that the desoxyribosenucleotide had been converted into the nucleoside.

The desoxyribosenucleosides were also chromatographed with the four solvent systems, and finally, mixtures of the fractions with the compounds they were thought to contain were chromatographed. From the results given in Table III, it was concluded that fractions I and II contained the

TABLE II

PURINE AND PYRIMIDINE DERIVATIVES TESTED FOR ABILITY TO REPLACE VITAMIN B_{12} FOR *Lactobacillus leichmannii**

Purine or pyrimidine	Growth test carried out with				
	Free base	Desoxyribose-nucleoside	Desoxyribose-nucleotide	Ribose-nucleoside	Ribose-nucleotide
Adenine	−	+	±	−	−
Guanine	−	+	±	−	−
Hypoxanthine	−	+	**	−	−
Xanthine	−	**	**	−	−
Cytosine	−	+	±	−	−
5-Methyl-cytosine	−	+	±	**	**
Uracil	−	+	**	−	−
Thymine	−	+	±	**	**
6-Methyl-uracil	−	**	**	**	**

* *Medium: Difco-CS vitamin B_{12} agar.*
** *Compound not available.*
\+ *Positive growth test.*
± *Very slightly positive test.*
− *Negative growth test.*

TABLE III

R_F VALUES OF FRACTIONS AND PURE DESOXYRIBOSENUCLEOSIDES

Compound	Solvent system			
	BuOH/water	BuOH/ammonia	Isoamyl alcohol /Na_2HPO_4	BuOH/ethyl acetate/morpholine
Desoxyriboside of:				
Guanine	0.21	0.15	0.58	0.54
Hypoxanthine	0.23	0.12	0.66	0.50
Cytosine	0.23	0.28	0.73	0.67
5-Methyl-cytosine	0.25	0.32	0.80	0.70
Adenine	0.43	0.45	0.42	0.77
Uracil	0.41	0.25	0.75	0.91
Thymine	0.51	0.48	0.71	0.95
Xanthine	—	0.05*	—	—
Fraction				
I	0.51	0.50	0.71	0.95
II	0.39	0.28	0.75	0.89
III	0.22	0.10	0.66	0.52
IV	0.20	0.05	0.60	—
Fraction				
I+TDR	0.51	0.48	0.71	0.96
II+UDR	0.39	0.28	0.75	0.88
III+HDR	0.23	0.13	0.67	0.52

* *From McNutt, W. S. Biochem. J. 50: 384. 1952.*

desoxyribosides of thymine and uracil respectively. Chromatography of fraction III always produced elongated zones, indicating lack of homogeneity. With *n*-butanol/ammonia, these zones could be divided into two, not clearly separate, fractions with R_F 0.12 and 0.18. The first component could not be distinguished from the desoxyriboside of hypoxanthine and the second showed the same chromatographic behavior as guanine desoxyriboside. The component of fraction IV is probably identical with xanthine desoxyriboside, inasmuch as its R_F value for *n*-butanol/ammonia agreed with the value given in the literature (8) for that compound and no other nucleoside with the same low R_F value was known. Definite proof could not be obtained because the pure compound was not available.

Discussion

When the results of this investigation are compared with data on beef liver (6, 7, 9, 13, 14) it may be seen that the total vitamin B_{12} activity of both materials is due mainly to the presence of cyano- and hydroxo-cobalamin and for a small part to additional growth factors. The vitamin B_{12} activity of dried cod-liver residue is about as high as that of dried beef liver.

The additional growth factors are desoxyribosenucleosides in cod liver, as well as in beef liver, but whereas for materials of mammalian origin the derivatives of adenine, guanine, and cytosine are expected (1, 15), the cod-liver residue was found to contain the desoxyribosides of hypoxanthine, uracil, and xanthine. It has not been established whether these compounds were present *in vivo* or were artifacts, formed by deamination and oxidation. The latter seems probable since the derivatives of adenine, guanine, and cytosine were found in preliminary work with fresh cod livers (5).

It may be concluded that the vitamin B_{12} activity and its distribution are very similar for cod-liver residue and beef liver, hence that cod-liver residues may be used to replace beef liver as a source of vitamin B_{12} in medicinal preparations and stock feeds.

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Platinum Oxide on Silicic Acid

Stable, Active Hydrogenation Catalyst

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Platinum oxide supported on silicic acid, a modification of the well-known Adams catalyst, is very active at room temperature yet is a very stable hydrogenation catalyst. The rate data obtained with the catalyst are reproducible and are of definite analytical value because they are dependent upon the chemical constitution of the material hydrogenated. In the determination of multiple bond unsaturation, its use is of advantage because it is conducive to short reaction times and sharp end points.

DURING the early stages of an investigation of the kinetics of catalytic hydrogenation undertaken previously in this laboratory, the main obstacle to satisfactory experimental work proved to be the instability of catalysts. This study concerned hydrogen absorption rates under normal conditions of temperature and pressure. The highly active catalysts needed for this type of work were prepared according to known procedures, most of them being obtained in the form of finely divided metals, such as platinum, palladium, or nickel, generally supported on some inert material and suspended in a solvent. A comprehensive review of the literature concerning this type of catalyst is now available (*3*, *4*).

In spite of elaborate precautions involving cold storage in an oxygen-free atmosphere, the activity of the catalysts declined much too rapidly for comparable data to be secured. Further difficulties were encountered with catalysts such as Raney nickel, which could not be measured in precise amounts even by pipetting from thoroughly stirred and seemingly homogeneous suspensions. Platinum oxide prepared according to Adams (*1*, *2*) was thought to offer a solution to this problem. It is easily prepared and can be weighed out accurately. On reduction with hydrogen, it readily provides a highly dispersed and very active form of platinum, which can be obtained *in situ* just prior to the introduction of unsaturated compounds. It is therefore not exposed to the effects of prolonged storage as is the case with most catalysts. Indeed, as determined from the behavior of equal amounts of the same platinum oxide preparation tested over a period of several weeks, only a slow over-all decline in activity was observed; the variation from run to run, however, was

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appreciable. It was obvious from the examination of samples which had displayed a particularly low activity that a change had occurred in the catalyst structure. The normally dispersed platinum microcrystallites had gathered to form agglomerates of variable size which settled rapidly when stirring was interrupted. The effect on the active area of this uncontrollable phenomenon is similar to that observed with other catalysts as a result of sintering through overheating.

It was thought that this tendency might be suppressed or at least minimized if platinum oxide was bound to a catalytically inert support. Martin (*6*) had described the preparation of supported platinum oxide catalysts for industrial use. These were not found active enough to warrant their use in this investigation.

A suitable catalyst could be prepared by including silicic acid in the preparation of the well-known Adams catalyst and by modifying the classical procedure to some extent. This new catalyst offers potential advantages to the analytical chemist. A few illustrative cases have been selected from the extensive data obtained through the use of the catalyst in a kinetic investigation to be reported at a later date.

All the data presented here resulted from experiments carried out at 25° C. and 760-mm. pressure, using the apparatus and techniques described earlier (*9*). One important feature of the apparatus is to allow control of the rate of hydrogen diffusion to the reaction medium by adjustment of the stirring. When stirring efficiency is increased beyond a certain point, hydrogen concentration in the medium remains constant—i.e., at the saturation value corresponding to the temperature and pressure used. Under these conditions, the variables affecting the rate of hydrogenation are the concentrations of unsaturated compounds initially involved, those of intermediate products, if any, and in some cases those of end products.

Application of the known simple tests to the absorption-time data invariably failed to reveal a simple relationship between rate and unsaturated compound concentration. This is in contrast to data obtained with catalysts such as Raney nickel (*9*), where a first-order relationship can be found. However, plotting the rate against the corresponding total unsaturation yielded characteristic curves which were used to establish the dependency of absorption rates on the variables listed above. In all experiments, the buret was read every minute and the rate at time t was taken as the average of the volumes absorbed at times $t - 1$ and $t + 1$. In spite of a small systematic error, this method proved to be more precise and more expeditious than the application to the time-absorption curves of the graphical tangent procedure. The total unsaturation at time t was taken as the corresponding volume of hydrogen still to be absorbed for complete reduction—i.e., the difference between the volume corresponding to complete saturation and that absorbed at the time considered.

PREPARATION

Seven grams of C.P. chloroplatinic acid are dissolved in 25 ml. of distilled water in a 100-ml. borosilicate glass beaker. Twenty

grams of 200-mesh fraction No. 2847 silicic acid (Mallinckrodt) are added, and the whole is stirred with a glass rod until a smooth paste is obtained. The beaker, supported by a metal gauze, is placed over a burner and cautiously heated with continuous stirring until the mass is completely desiccated. The resulting powder is added by small portions with continuous and rapid stirring to 70 grams of molten C.P. sodium nitrate at 350° C. This is achieved by heating a 250-ml. beaker containing the nitrate with a strong flame, somewhat broader than the bottom of the beaker so that the walls are heated as well. Each addition of powder to the melt induces a temporary release of reddish nitrogen oxide fumes and a frothing of the mass. Additions are so spaced as to avoid any rising of the froth higher than about 1 inch above the original level. When all the powder has been added, any material which has solidified on the walls is melted, by use of an auxiliary heater, and is pushed down into the melt with the stirring rod. Heating and stirring are continued until gas evolution has practically ceased. The beaker is held with tongs while the contents are slowly poured into a 2-liter beaker containing 1.5 liters of distilled water, agitated by a mechanical stirrer. Another 20 grams of sodium nitrate are melted in the 250-ml. beaker. The melt is used to rinse the walls with the help of the glass rod, and then poured into the water. The beaker is allowed to cool, then it is washed with distilled water. The washings are added to the bulk of the preparation, which is stirred for 2 hours and allowed to settle overnight. As much clear supernate as possible is siphoned off and the residue equally distributed in centrifuge tubes. Water is added and the contents of each tube are well stirred with a glass rod. After centrifuging, the clear supernate is poured off and replaced by distilled water. The preceding operation is repeated until the washings show just a faint pink coloration with phenolphthalein. The preparation is then transferred to a medium-porosity sintered-glass funnel with a minimum of water, and the liquid is filtered off. It is twice replaced by 95% alcohol, then ether. After being air-dried for 1 hour, the product is transferred to a vacuum desiccator containing phosphorus pentoxide.

The dried material is transferred to a small mortar, where it is easily pulverized, and then in small portions to a 200-mesh sieve. A camel's-hair brush is used to move the powder over the gauze. Any residue is reground and sieved until everything has passed through.

The light-brown powder is stored in a screw-capped bottle and well mixed before use.

The yield is 21.0 grams, containing 0.14 gram of platinum per gram of the material.

STABILITY

Microscopic examination of the reduced catalyst (PS 14) shows the platinum microcrystallites firmly embedded in the support. This markedly increases their stability. A sample of the catalyst, stored in a frequently uncorked bottle and exposed to full daylight for more than 2 years, has not sustained any appreciable loss of activity. Moreover, structural changes, such as previously observed with unsupported platinum, do not occur while the catalyst is being used. One immediate consequence of this high stability is the reproducibility of hydrogenation rate data, which is required for reliable analytical results.

ACTIVITY

Weight for weight, the platinum oxide in PS 14 is 2.5 times more active than the best Adams catalyst prepared in this laboratory, as judged by the time required for the complete saturation of a variety of olefinic compounds.

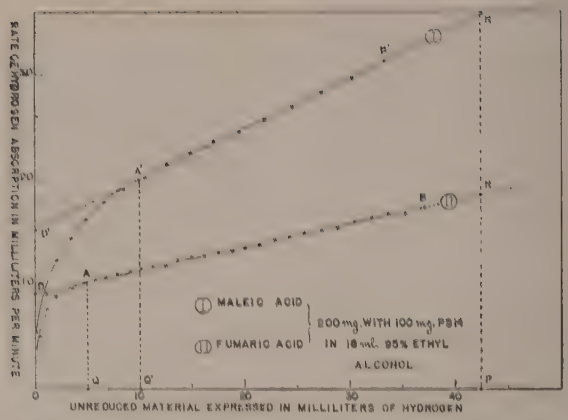
RATE OF HYDROGEN ABSORPTION IN MILLILITERS PER MINUTE
UNREDUCED MATERIAL EXPRESSED IN MILLILITERS OF HYDROGEN
① MALEIC ACID
② FUMARIC ACID
200 mg. WITH 100 mg. PS14 IN 16 ml. 95% ETHYL ALCOHOL

Figure 1. Hydrogenation rate curves of maleic and fumaric acids obtained under the same conditions

A comparison made with Raney nickel W-5 (*2*) in the reduction of long-chain unsaturated fatty esters shows PS 14 to be much more active. With only 20 mg. (3 mg. of platinum), the time required to reduce 256 mg. of methyl oleate was 11 minutes; with Raney nickel containing 191 mg. of nickel, the time to reduce 192 mg. of methyl oleate was 61 minutes. Half saturation of 254 mg. of methyl linoleate was attained in 5 minutes using 20 mg. of PS-14, while a sample of Raney nickel containing 200 mg. of nickel required 10 minutes to half saturate 192 mg. of the same ester. These data were selected from a series of experiments carried out in 95% ethyl alcohol.

Under these same conditions the benzene ring in phenol, benzoic acid, cinnamic acid, and benzamide is completely reduced in less than 2 hours, provided larger amounts of PS 14 are used.

Figure 1 shows the absorption rate curve when pure maleic acid (curve I) and pure fumaric acid (curve II) are hydrogenated in 95% ethyl alcohol. Both are typical of most curves obtained under these conditions. Curve II, for instance, displays two branches, *OA* and *AB*, distinct in character. Branch *AB*, which is a straight line, allows the initial rate *PR* to be obtained by extrapolation, as shown by the dotted lines. Thus *PR* is the ordinate corresponding to zero time for fumaric acid; *PR'* is the corresponding value for maleic acid. When these initial rates are plotted against amounts of catalyst used, straight lines passing through the origin are obtained, as shown in Figure 2. In the case of fumaric acid, somewhat higher values of the initial rates are obtained with higher initial concentrations of this acid; a 10% variation is observed when the amount of acid used varies between 50 and 200 mg. or when the volume of alcohol varies between 10 and 20 ml. With maleic acid only a 2% variation of the initial rate is observed within the same range of conditions. Thus, the initial rate corresponding to maleic or fumaric acid for one unit weight of catalyst affords a convenient way of defining the activity of a given sample.

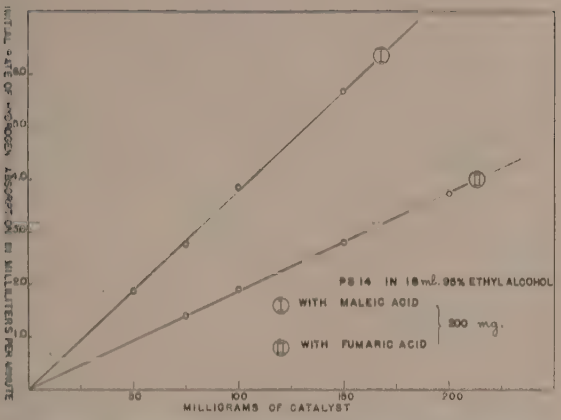

Figure 2. Amount of catalyst *vs.* initial rate plots for maleic and fumaric acids, showing simple proportionality

The advantage of maleic acid in yielding initial rate values practically independent of the initial acid concentration within relatively wide limits is offset, however, by the somewhat elaborate procedure (*5*) required to obtain the acid in a pure state. (The chemical which is sold as pure maleic acid is a mixture of the two stereo isomers.) Fumaric acid is stable, easily purified, and chemically well defined, and is thus to be preferred as a standard. As a measure of activity, called "fumaric acid value," the initial rate of absorption expressed in milliliters of hydrogen has been adopted. This is the value observed when 100 mg. of catalyst is used with 100 mg. of pure fumaric acid in 15 to 20 ml. of 95% ethyl alcohol under normal pressure at 25° C. The use of fumaric acid values should allow a direct comparison of results obtained in different laboratories. When the activities for the same unsaturated compound of two different samples of PS 14 (measured as initial rates obtained with equal amounts of the two samples) are determined, the ratio of these activities is usually found equal to the ratio of the corresponding fumaric acid values.

SELECTIVITY

Although the benzene ring in cinnamic acid is completely reduced, the reaction is much slower than the reduction of the side chain. A sharp break appears on the hydrogenation rate curve, clearly indicating the disappearance of the aliphatic double bonds; thus, it is possible to determine both aliphatic and aromatic unsaturation from the same experiment.

The benzene ring in phenol, benzoic acid, and benzamide is also reduced; it is left intact in phenol ethers and in alkyl benzoates. In aryl substituted alkenes and aryl substituted olefinic esters, only the side chain is reduced.

In 95% alcohol, PS 14 displays little selectivity in the reduction of polyunsaturated fatty acids and esters. If, however, the hy-

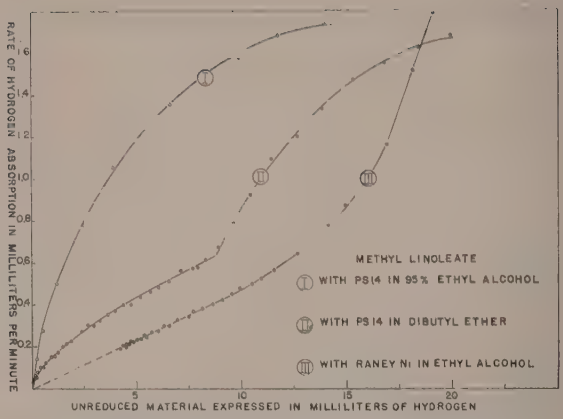
RATE OF HYDROGEN ABSORPTION IN MILLILITERS PER MINUTE
UNREDUCED MATERIAL EXPRESSED IN MILLILITERS OF HYDROGEN
METHYL LINOLEATE
I WITH PS14 IN 95% ETHYL ALCOHOL
II WITH PS14 IN DIBUTYL ETHER
III WITH RANEY Ni IN ETHYL ALCOHOL

Figure 3. Hydrogenation rate curves obtained with methyl linoleate, showing differences in selectivity

drogenation is carried out in dibutyl ether, there is a marked selectivity comparable to that observed with Raney nickel in 95% alcohol. This is exemplified in Figure 3, which shows three rate curves obtained with methyl linoleate. Curve I corresponds to PS 14 in 95% alcohol; it does not show the characteristic break indicating saturation of the 12-13 double bond observed in curves II and III, which were obtained with PS 14 in dibutyl ether and with Raney nickel in 95% ethyl alcohol, respectively.

Another type of selectivity is indicated by curves I and II in Figure 1. These were obtained with the same amounts of PS 14 and of the acids, in the same volume of 95% ethyl alcohol. Thus, maleic acid is reduced about twice as fast as its trans isomer.

Ethyl esters of these acids are reduced more slowly than the corresponding acids.

FACTORS INFLUENCING SELECTIVITY

The marked solvent effect upon selectivity described above for methyl linoleate is but one particular case of a more general phenomenon. The hydrogenation rate of any double bond is influenced by the reaction medium. For instance, while 20 mg. of PS 14 requires only 11 minutes to reduce 256 mg. of methyl oleate in 95% alcohol, 19 minutes are required in dibutyl ether to saturate 152 mg. of the same compound. This solvent effect may stem from many different causes. In this particular case it is due to the stronger adsorptive competition on the catalyst surface of the fully reduced compound. When increasing amounts of methyl stearate are deliberately added to identical mixtures of methyl oleate, dibutyl ether, and reduced catalyst, the observed initial hydrogenation rates are found to decrease with increasing amounts of the additive. Only a small decrease in rate is observed, on the other hand, when succinic acid is added to a reaction mixture containing either fumaric or maleic acid in 95% alcohol.

EFFECT OF INORGANIC ACIDS AND BASES

Attempts were made to speed up the removal of alkali from the freshly prepared unwashed catalyst, by neutralizing an aqueous suspension with inorganic acids to pH 7. This accelerated the final washing, but resulted in a very poor catalyst.

When very small amounts of sodium hydroxide are added to the 95% ethyl alcohol used as a solvent for the reduction of fumaric acid, an increase in activity is first observed. A maximum increase is reached for a 0.002*N* alkali concentration in the alcohol: There is a definite swelling of the support and an expansion in active area of about 100% as judged from the increase in hydrogenation rate. However, as the alkali concentration is further increased, the support gradually deteriorates and the activity declines. With a 0.05*N* solution, the catalyst no longer disperses normally throughout the reacting mixture, but forms a heavy flocculate having less than one fifth the activity of the normal catalyst.

Thus, both inorganic acids and bases affect the activity, apparently by inducing structural changes in the support. No satisfactory substitute for silicic acid has yet been found. Therefore the use of PS 14 should be avoided in strongly basic or acid reaction mixtures.

APPLICATIONS

Less than 20 minutes are usually needed to complete a quantitative determination of multiple bond unsaturation. Much larger amounts of other less active catalysts normally require 1 hour under the same conditions. This rapid and complete reaction is also characterized by a very sharp end point; there is no dragging of the absorption toward the end as with other catalysts. That this occurs with Raney nickel W-5 is shown in the following example: fifteen hours were required with 20.3 mg. of nickel (in the form of Raney nickel W-5) to reduce 250 mg. of methyl oleate in alcohol. The last 0.18 ml. of hydrogen was absorbed in just over 1 hour. When 10 times that amount of catalyst was used, the total time was reduced to 61 minutes, 0.24 ml. being absorbed in the last 10 minutes. In contrast with this, only 3 mg. of platinum (20 mg. of PS 14) were needed to hydrogenate 286 mg. of the same ester in 11 minutes, 0.51 ml. being absorbed in the last 2 minutes. On the basis of rate of hydrogen absorbed and weight of metal used, it would appear that the platinum in PS 14 is over 500 times more active than the nickel in Raney nickel.

Admittedly approximate, this figure indicates, however, a considerably higher activity at low concentration of unsaturated compound. Such a property is particularly desirable for hydrogen value determinations.

Comparative experiments carried out on a variety of compounds have shown it to be general in respect to double bonds under the conditions used. The superiority of platinum catalysts over nickel catalysts has been explained (*8*) on the basis of closer matching between atom spacing in the metal and carbon-carbon spacing of the unsaturated bond.

The extensive literature on batch-type catalytic hydrogenation under normal temperature and pressure includes an appreciable amount of hydrogenation rate data. Whether these data have any significance other than a qualitative one is doubtful. Most of them were obtained with catalysts, the activity of which could not be maintained constant long enough to allow these data to be duplicated. Furthermore, they were seldom recorded under all desirable conditions. By using an apparatus which allows such conditions to be established (*4*) it is possible to demonstrate that hydrogenation rate curves cannot be duplicated when these catalysts are used. Those obtained with PS 14, on the other hand, can be duplicated even after many months.

Such curves have interesting characteristics. Curve II in Figure 1 is typical of mono-olefinic compounds in ethyl alcohol. The initial rate PR, the coordinates of point A, the intercept OD, and the slope of line AB are all related to the particular type of double bond involved in the reaction. The position of this bond in the molecule; the presence, nature, and location of substituents; and the presence of activating functional groups influence the values of the above characteristics. For the initial rate alone there is a wide range of values from zero (benzenic unsaturation, in some cases) to a very high one (allylic unsaturation).

With test materials containing different types of double bonds, the curve may, when the proper medium is used, show characteristic breaks such as in curves II and III, Figure 3. Such curves allow the quantitative estimation of the different double bonds by comparison with standard curves, which are established by using mixtures containing known amounts of the same constituents.

The full advantage of these properties may not be generally appreciated until a reasonably complete and systematic exploration of PS 14 behavior toward unsaturated compounds has been accomplished. Such a task requires access to a considerable number of pure, not commercially available, chemicals.

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A PARASITIC COPEPOD (*SALMINCOLA FALCULATA*) ATTACHED TO A FISH HEART

Copepods of the genus *Salmincola* are frequntly found on salmonid fishes attached to the skin, fins, gills, and the membranes of the mouth and branchial cavity. An unusual case of attachment to the heart was found recently during a routine examination of a number of young sockeye salmon, *Oncorhynchus nerka*. The specimen was small compared with individuals found on the skin and gills of other fish from the same sample, but on the basis of the structure of its appendages appears to be *Salmincola falculata* (Wilson).

As shown in the accompanying photograph, the copepod lay dorsal to the heart with one edge of its bulla firmly attached to the wall of the auricle. The location of the body of the parasite is uncertain as the copepod was not noted until the heart had been removed and examined under a dissecting microscope. It may have been present in either the pharynx or

branchial chamber with the pedicel of the bulla passing through the thin tissues which separate these regions from the pericardial cavity. However, the less probable occurrence of the entire copepod within the pericardial cavity cannot be ruled out.

The host was a downstream migrant from Cultus Lake, British Columbia, collected on April 20th, 1955. Its fork length of 8.4 cm. was well within the range of length for other fish in the sample. No evidence of pathological effects was noted.—James R. Adams, *Department of Zoology, University of British Columbia, Vancouver, and Pacific Biological Station, Nanaimo, B. C., Canada.*

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PULP MILL POLLUTION IN ALBERNI HARBOR, BRITISH COLUMBIA

By Michael Waldichuk

Fisheries Research Board of Canada, Pacific Biological Station, Nanaimo, British Columbia, Canada

The original study of oceanography in Alberni Inlet was conducted by Tully (1) to predict the effect of pulp mill effluent discharge on the biotic environment of the inlet. The results of this study prompted industry to reconsider the process to be used in their pulp production. In place of the sulfite mill originally planned, from which it was evident a high degree of pollution would be discharged during the summer months, the company installed a sulfate (Kraft) mill. Since 1948, this mill has been discharging wastes from a production of up to 230 tons per day into the head of Alberni Inlet at the estuary of the Somass River. Following the first months of operation, water samples taken at a few strategic points showed no deficiency of dissolved oxygen (2). No complete survey of the inlet waters was made at that time.

A new management announced its intentions to expand the mill to a capacity of 500 tons per day of unbleached Kraft pulp and 500 tons of newsprint (mainly groundwood). It was desirable, therefore, to observe the effects of the discharge from the existing mill on Alberni Inlet water in order to predict the effect of the effluent from the planned expansion. This paper presents some of the results and considerations of the survey conducted in September, 1954.

Situated on the west coast of Vancouver Island, Alberni Inlet is connected to the Pacific Ocean by Barkley Sound. The harbor is relatively shallow with a maximum depth of 19 fathoms (114 ft.) shoaling into extensive tidal flats at the north end. The Somass River, discharging into the northeast end of the harbor, has been responsible for the tidal flats and marshlands in that area through deposition of its silt load. The condition of the water in the harbor is of concern from a fisheries point of view, in that substantial runs of several species of Pacific salmon and sea-run trout support a small commercial fishery as well as a popular sport fishery. The spawning migrations of most of these anadromous fishes to the tributary rivers of the Somass River occur during the period of low runoff in late summer, when the effects of pollution are at a maximum.

Survey Technique

The survey was conducted during the week, September 7 to 11, 1954. Samples for salinity, dissolved oxygen, pH and lignin determinations were taken at the surface, 6, 15, 30, 45, 60, 90 ft., and near bottom (or at as many of these levels as the depth permitted). Sampling bottles of the Fjarlie design (3) were used for subsurface samples. Dissolved oxygen and pH determinations were carried out on board ship within 24 hr. after the samples were taken. The procedure described by Tully (1) for shipboard dissolved oxygen analysis was used. A Beckman pH meter was employed for the pH determinations.

The nitrosolignin test for sulfite waste liquor, described by Pearl and Benson (4), was employed to determine Kraft waste concentration as

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lignin. A Klett-Summerson colorimeter with No. 54 filter and 45 mm. cell was used to measure the color intensity. Color of the water and depth of light penetration were examined with a standard, white 30-cm. diameter Secchi disc. The bottom materials in the harbor were checked with a sounding lead and tallow by the standard method (5).

The survey period normally is a time of small runoff, but 1954 was an anomalous year with precipitation all during the summer. Consequently, the Somass River discharge computed from the sum of Stamp and Sproat Rivers did not reach its usual low point of less than 500 c.f.s.

Observed Characteristics

Distribution of properties at the surface in Alberni Harbor is illustrated in Figures 1 and 2. Salinities throughout the harbor, Figure 1, ranged from 5 to 10 parts per thousand (‰).

A very crudely determined distribution of effluent in the surface water is shown in Figure 1. The distribution of effluent was characterized by patchiness. High concentrations were found in thin patches along the waterfront. Generally the high concentration was separated from the well diluted mixture by a foam line. The concentration of effluent fell off to 2 per cent at the surface in less than one-half mile from the outfall. Smaller concentrations could not be measured satisfactorily by the technique used.

A surface oxygen distribution illustrated in Figure 2 combines data obtained from regular Stations L20, 1, 2, 3, 4, and 5 occupied on September 9, 1954, with surface samples collected

FIGURE 1.—Salinity and pulp mill effluent in the surface water of Alberni Harbor.

FIGURE 2.—Dissolved oxygen and pH values of the surface water of Alberni Harbor.

from the area surrounding the pulp mill outfall on September 10. There was a general increase of dissolved oxygen from the outfall area seaward. Except in the immediate vicinity of the outfall, dissolved oxygen concentration in excess of 5.0 mg. per liter occurred throughout the harbor.

The pH value distribution shown in Figure 2 generally corresponded to the dissolved oxygen trend in the main part of the harbor. In the outfall area, however, the pH value increased as the concentration of effluent increased. The effluent reaching the sea had a pH of 11.3, but this rapidly decreased as dilution occurred. Sea water is a solution of numerous buffering salts so that any acidic or alkaline constituents added are rapidly restored to near neutrality. Somass River water had a pH of about 7.5 which was generally lower than that of sea water. Consequently, in the area outside the outfall there were at least four factors which influenced the pH value: (a) the effluent with a high pH; (b) river water with a relatively low pH; (c) oxidation of the effluent reducing the pH; and (d) the buffering action of sea water with a pH value of about 8.0.

The vertical distribution of properties in the harbor is shown in Figure 3. The salinity chart, Figure 3a, shows the very pronounced gradient in salinity for the upper 15 ft., with a salinity at 20 ft. comparable to that of the deep water in Barkley Sound. The temperature chart, Figure 3b, followed a similar pattern, with a 12° F. gradient in the upper 30 ft. Water below 30 ft. depth, actually was cooler than the water at the same level in Barkley Sound. This suggests that the deep

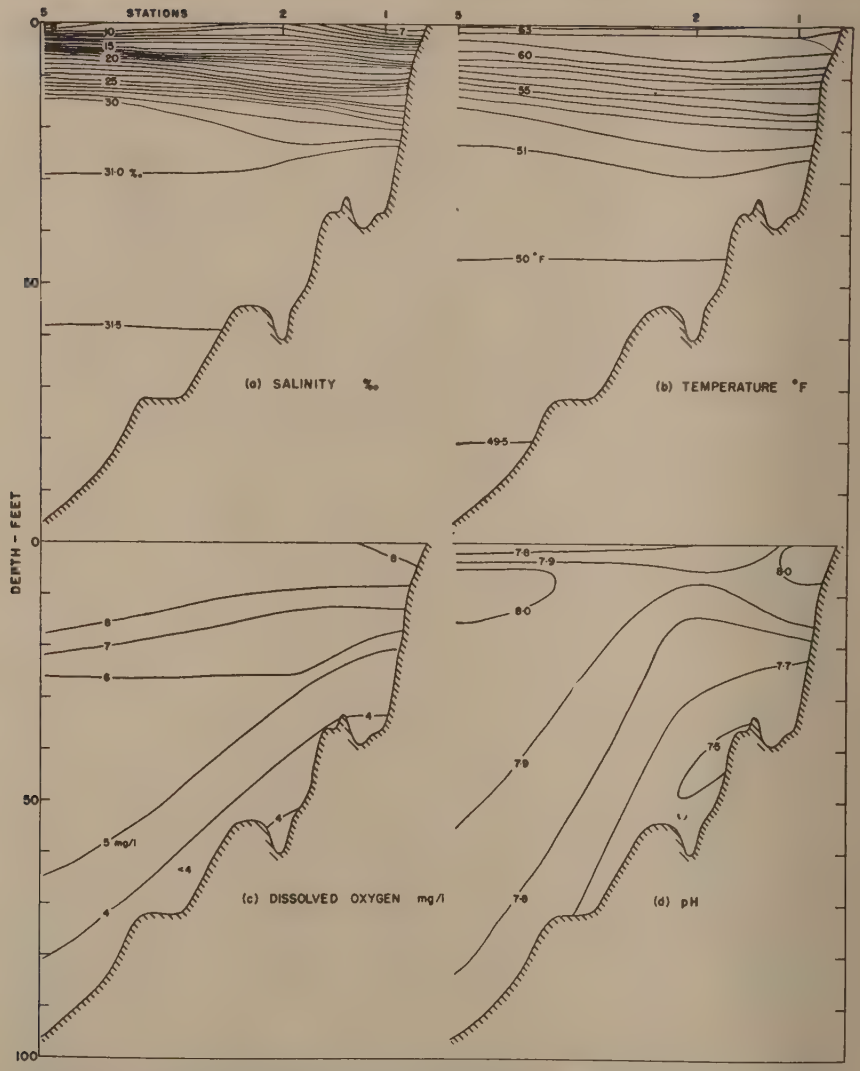

FIGURE 3.—Vertical distribution of characteristics in Alberni Harbor: (a) salinity, (b) temperature, (c) dissolved oxygen and (d) pH value.

water in the inlet had not been subjected to an increase in temperature by thermal conduction, currents or mixing from the time it first entered the deep zone in Alberni Inlet. In the meantime, the outside water had been receiving heat to considerable depth by wind and tidal mixing.

The oxygen distribution illustrated in Figure 3c shows the low oxygen concentration in the deep water (less than 4 mg. per liter). Slope of the iso-oxys upward to the northern end of the harbor indicates either movement of deep water toward the surface, to replace sea water being swept

away by the seaward flow of fresh surface water, or a depletion of oxygen in a constant depth above the bottom.

The pH distribution in Figure 3d shows a distinct conformity to the oxygen distribution, with a similar upward trend in the isopleths of pH in the deep water. The highest pH of 8.0 was found at a depth of 10 ft. where relatively uncontaminated sea water occurred.

Character of Pulp Mill Effluent

The MacMillan and Bloedel, Limited, pulp mill in Port Alberni produces 230 tons of unbleached Kraft pulp per day with a waste discharge of 28,000 gal. per ton. This gives a total effluent discharge of 6.44 m.g.d. Based on its B.O.D. which has been experimentally determined to be 150 p.p.m. (6) the total oxygen demand of these wastes is 35 lb. per ton of pulp. In terms of a population equivalent given as 0.168 lb. oxygen per capita per day (7), this production amounts to the oxygen demand of 208 persons per ton of pulp or a total population of 47,840 for the daily production.

The effluent from the pulp mill flows in an open channel through a fairly extensive meadow and marshland in its course from the mill site to the sea, receiving considerable aeration during its turbulent flow. On reaching the sea the effluent is at a temperature of about 80° to 90° F., and is completely devoid of dissolved oxygen.

Behavior of Effluent in Harbor

The effluent flows over the sea water in a thin (2 to 6 in.) layer immediately beyond the outfall. This was apparent in the large temperature gradient from the warm surface layer (86° F.) to the deeper water (68° F.) which could be measured in the length of an ordinary 10-in. thermometer. Mixing of this surface layer into the sea water occurs beyond a foam line region surrounding the outfall in a radius of about 100 yd.

The foam line marks a sharp gradient between the warm, dark brown, low-salinity and low-oxygen mixture on the outfall side and the dilute mixture approaching sea water conditions on the seaward side. Evidently the stability of the effluent on the sea water breaks down beyond this foam line boundary. Observations were made on an extremely calm morning when the sea was glassy smooth. On a windy day the mixing would undoubtedly occur much closer to the outfall and the gradient would be less noticeable.

Bottom materials were observed with sounding lead and tallow for lack of better sampling gear. Conditions improved rapidly away from the outfall. Residues from the effluent, consisting mainly of white chalk-like materials with strata of black organic substance, appeared to settle out into a layer 2 to 5 ft. thick at the outfall. Beyond this region the bottom materials were largely coarse sand with gravel and fragments of bark. The river mouth showed no evidence of mill waste particulate matter having accumulated on the bottom.

The color of the water changed from dark brown immediately outside the outfall, where the Secchi disc could be seen only to a depth of 1 ft., to a brownish-green in the middle of the harbor (with a Secchi disc reading of 19 ft.). In the saw mill and log boom area the water had a reddish-brown tinge. The improvement of water color and light penetration was rapid outside the foam line.

Discussion and Summary

There is no oxygen shortage in the surface water of Alberni Harbor except in the immediate vicinity of the pulp mill sewer outfall. The recommendation of Tully (1) to maintain the sewer discharge at the surface seems to have been a good one, inasmuch as advantage is taken of the

seaward flow, high dissolved oxygen in the surface water, as well as wind aeration. Deep water is already depleted of oxygen and would not support much oxidation of foreign material.

On the basis of work by Tully (1) the daily oxygen provided by the fresh water and sea water mixed in the upper zone at the discharge of the Somass River during the survey (1,245 c.f.s.) is 100,000 lb. The oxygen required for effluent oxidation is 8,000 lb., leaving 92,000 lb. in the water. This amounts to an average of 6.8 mg. per liter when spread over the entire harbor, a good check with the observed results and well on the safe side for fish requirements. Although the survey was conducted during the period of normally low Somass River discharge, the 1954 season cannot be considered as representative. Ordinarily much lower discharges are met during this period and far less oxygen is available.

Variations in pH are too small to be of any consequence to the fish. The buffering capacity of sea water maintains the pH close to 8.0 at all times. Only in the region of high effluent concentration and low dissolved oxygen were pH values much in excess of 8. It has been established that a tolerable pH range for most fish is 5.0 to 9.0 (8).

Observations of mill waste concentration have borne out results reported on model experiments using dye as a tracer (1)(9). The midharbor area in the path of the jet stream from the Somass River appears to be well flushed and relatively free of pollutant. Northwest and northeast corners of the harbor, however, are occupied by back eddies which tend to accumulate and stagnate the effluent.

It can be generally concluded that there is no serious condition of pollution in Alberni Harbor at the present time from a fisheries point of view. The possibility does remain, however, that it is the toxicity of the effluent in high concentration and not just its oxygen demand which may be of primary concern after expansion of the pulp mill.

Dissolved oxygen concentration and pH are normal everywhere except in the immediate vicinity of the mill sewer outfall. Discharge of mill wastes at the surface of the inlet instead of at depth prevents further depletion of the oxygen in the deep water already low in oxygen content as a result of natural causes. Concentration of the pulp mill effluent was quite high in the surface water at the mouth of the Somass River. This situation is probably too short-lived, occurring only on the flood tide and during calm weather, to be of any consequence to the fishery.

Acknowledgments

The data were collected from C.N.A.V. *Ehkoli* through the courtesy of the Pacific Naval Laboratory and the Pacific Oceanographic Group. MacMillan and Bloedel, Limited, have kindly permitted the use of their production data to characterize the mill effluent.

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NUTRITION AND METABOLISM OF MARINE BACTERIA

II. OBSERVATIONS ON THE RELATION OF SEA WATER TO THE GROWTH OF MARINE BACTERIA[1]

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Marine bacteria have been arbitrarily defined as bacteria from the sea which on initial isolation require for growth a medium containing sea water as the diluent (ZoBell and Upham, 1944). The function of sea water in media for the growth of these organisms has never been clearly established. It has been stated, however, that neither isotonic salt solution nor artificial sea water is as good as natural sea water for the cultivation of recently isolated marine bacteria (ZoBell, 1946).

The nutritional requirements of a number of marine bacteria have been determined recently (MacLeod *et al.*, 1954). In the course of this study it was found that a mixture of inorganic salts approximating the composition of sea water could be used in place of natural sea water in a chemically defined medium suitable for the growth of these organisms. A limited amount of information regarding a requirement of the bacteria for specific inorganic ions was also obtained.

The present report presents the results of a more detailed study of the relation of the constituents of sea water to the growth of marine bacteria.

METHODS

Cultures. The sources of the organisms and the general methods used in their study have been described (MacLeod *et al.*, 1954). Six of the organisms used in the previous study were selected for this work. The organisms used have been tentatively identified as B9, a flavobacterium; B10 and B20, corynebacteria; B16 and B26, mycoplana; and B30, a pseudomonad. Their organic growth requirements are known and were reported in the previous communication. The organisms all satisfy the criteria established for classifying them as marine bacteria, that is, on initial isolation they grew in a complex medium prepared with sea water, but not with fresh water.

Inocula. The inoculum medium used has been described previously (MacLeod *et al.*, 1954). In this study cells were washed by centrifuging, removing the supernatant liquid and resuspending them in 1.097 M glycerol solution. This washing operation was repeated twice and one drop of the final suspension used to inoculate each flask. The concentration of glycerol in the wash solution was equal to the total molar ion concentration of sea water.

Basal medium.[2] This medium was the simplest capable of supporting the growth of all six organisms. All solutions were prepared using water demineralized by passage through a bed of ion exchange resins (Bantam demineralizer, Barnstead Still & Sterilizer Co., Boston, Mass.). The inorganic salts used were of reagent grade quality and were employed after recrystallization from demineralized water. The three amino acids were recrystallized from a solution adjusted to pH 2 to 3 with HCl. Glucose was purified by consecutive passage through "amberlite IRC-50" (H form) and "amberlite IR-4B" (OH form) ion exchange resin columns. Glycerol was distilled under vacuum in an all-glass apparatus before use. The NH_4OH and HCl solutions for neutralizing the medium were prepared by dissolving NH_3 and HCl gases, respectively, in demineralized water.

Assay procedure. The procedures used in this study differed from those employed previously (MacLeod *et al.*, 1954) in only one important respect. In this investigation the growth response in a particular assay was measured at frequent

[1] A preliminary report of these findings was made at the Ninth Science Conference, B.C. Academy of Science, University of British Columbia, April 28 and 29, 1955.

[2] Composition of the basal medium (in mg per 10 ml of final medium): Glucose, 30 mg; DL-α-alanine, 24 mg; DL-aspartic acid, 9.6 mg; L-glutamic acid, 12 mg; $(NH_4)_2SO_4$, 8.7 mg; $(NH_4)_2HPO_4$, 1.3 mg.

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TABLE 1

Comparison of the ability of natural sea water, artificial sea water and fresh water, when each is acting as the diluent in a chemically defined medium, to promote the growth of six marine bacteria

Diluent	Strength	Fe^{++} Added	Organism Tested											
			B9		B10		B16		B20		B26		B30	
			Incubation time (hr)											
			71	144	71	144	71	144	71	144	71	144	71	144
			Per cent incident light transmitted†											
		μg/10 ml												
Natural sea water	Full*	0	78	75	100	86	72	50	16	—	93	83	100	85
Natural sea water	Full	50	19	21	90	21	28	30	2	—	87	29	98	80
Natural sea water	Half	0	66	53	58	36	73	59	36	—	68	51	58	35
Natural sea water	Half	50	19	20	5	24	30	50	27	—	19	20	29	49
Artificial sea water	Full	0	54	50	97	70	77	52	56	—	92	82	93	80
Artificial sea water	Full	50	25	23	100	85	56	31	11	—	89	71	92	67
Artificial sea water	Half	0	72	68	34	71	82	56	30	—	64	56	65	48
Artificial sea water	Half	50	19	21	12	50	32	62	28	—	16	22	21	49
Distilled water	—	—	100	100	100	100	100	100	100	—	100	100	100	100

* Salinity: 35.4 g total salts per kg.

† Evelyn colorimeter readings, 660 mμ filter, uninoculated blank = 100.

intervals during incubation instead of after a fixed period of incubation. The variation in procedure was made possible by the use of 50 ml Erlenmeyer flasks, to each of which a matched 18 by 150 mm pyrex culture tube had been attached. By tilting the contents of the flask into the side tube at appropriate intervals, and inserting the side tube into a colorimeter, measurements of the change in turbidity of a culture with time could be made without danger of contamination (Sherman and Grant, 1951). Unless otherwise indicated, the results reported for each organism in each experiment were obtained after a period of incubation which resulted in the achievement of maximum growth by the organism. Certain of the organisms, however, autolyzed very rapidly after growth in the tubes had ceased. If growth of the latter organisms was slower in some tubes than in others, often some cultures would be autolyzing with a consequently decreasing turbidity while others were still growing. In these cases, results in the particular experiment were reported after a period of incubation which represented the best possible compromise between those cultures which were still growing and those which were autolyzing.

Salt solutions. The natural sea water used in these experiments was collected in the vicinity of Departure Bay, Vancouver Island. We are indebted to the Pacific Biological Station for making the sample available to us. Despite the fact that the sea water collection was made as far from land as possible, the salinity was below that considered average for the open sea. The sea water used was therefore evaporated to the desired salinity (35 to 40 g of total salts per kg) before use.

For the composition of the artificial sea water used in these experiments, see Lyman and Fleming (1940).[3]

RESULTS

The comparative ability of natural sea water, artificial sea water and fresh water when each is acting as a diluent in a chemically defined medium to promote the growth of the six marine bacteria investigated is shown in table 1. In this table, the results are reported after two periods of incubation except in the case of B20, which had reached maximum growth in all tubes in 71 hours. In certain cases it will be noted that the turbidity of a culture was less after 144 hours than after 71. This loss in turbidity on incubation was due to autolysis. The results show that growth of the organisms occurred in media prepared with

[3] Composition of artificial sea water used: NaCl, 23.476 g/kg; Na_2SO_4, 3.917 g/kg; $NaHCO_3$, 0.192 g/kg; KCl, 0.664 g/kg; KBr, 0.096 g/kg; $MgCl_2$, 4.981 g/kg; $CaCl_2$, 1.102 g/kg; $SrCl_2$, 0.024 g/kg; H_3BO_3, 0.026 g/kg.

both natural and artificial sea water, but not with fresh water. Relatively poor growth of all organisms except B20 was obtained in the media supporting growth unless a supplement of iron was added. The table also shows that for all of the organisms except B20 both the rate and extent of their growth was increased by using half rather than full strength sea water, irrespectively of whether the sea water used was natural or artificial. When both natural and artificial sea water were supplemented with iron and tested at half strength, there was no significant difference in the ability of the two diluents to promote growth of any of the organisms. In separate experiments it was also noted that natural and artificial sea water could be used interchangeably for growth of the marine bacteria in the complex medium used in their isolation. It would thus appear that the observed dependence of the marine bacteria investigated here on the presence of sea water in the medium on initial isolation was due to the ability of sea water to supply the inorganic environment required by the organisms for growth. There is no evidence that sea water was needed to supply unknown organic factors necessary or stimulatory for the growth of these marine bacteria.

When various groups of salts were omitted in turn from artificial sea water, the growth responses obtained with the various organisms are shown in table 2. It is evident that removing either Na^+ or K^+ salts completely prevented growth in all cases. When Mg^{++}, Ca^{++} and Sr^{++} salts were omitted, four organisms failed to grow and two grew only slightly. The removal of H_3BO_3 did not significantly affect the growth of any of the organisms. Since removing various salts, particularly the Na^+ and Mg^{++} salts, would render the solution hypotonic, the osmotic pressure of the solution was restored by adding a level of glycerol equal to the molar concentration of the total number of ions removed. In no case did the addition of glycerol permit growth of the organisms in the absence of the salts. It was established in separate experiments that none of the organisms could utilize glycerol as a source of carbon in the medium, and that cells harvested from a medium containing glycerol were unable to oxidize glycerol in a Warburg respirometer.

Since each of the omissions shown in table 2 involved more than one salt, it was of interest to know whether more than one salt in each group was required for growth by the organisms. Three sodium salts, NaCl, Na_2SO_4, and $NaHCO_3$, are used in the preparation of the artificial sea water.[3] NaCl and Na_2SO_4 were each added separately to a medium deficient in Na^+ salts at a level which provided Na^+ at the concentration normally made available by the mixture. $NaHCO_3$ could not be tested at this level because of the alkalinity of the resulting solution. The results (table 3) show that either salt was capable of satisfying the Na^+ salt requirements of all of the organisms if the period of incubation was

TABLE 2

Growth response of marine bacteria in the presence of glycerol when various salts are removed from the artificial sea water used as a diluent in the medium

Composition of Artificial Sea Water*	Glycerol Added†	Organism Tested					
		B9	B10	B16	B20	B26	B30
		Per cent incident light transmitted‡					
Complete	−	19	22	26	32	15	15
No Na^+ salts	−	100	100	100	100	100	100
No Na^+ salts	+	100	100	100	100	100	100
No K^+ salts	−	100	100	100	100	100	100
No K^+ salts	+	100	100	100	100	100	100
No Mg^{++}, Ca^{++} or Sr^{++} salts	−	100	100	100	100	91	81
No Mg^{++}, Ca^{++} or Sr^{++} salts	+	100	100	100	100	91	86
No H_3BO_3	−	19	13	24	28	15	17

* Supplemented with Fe^{++} 50 μg per flask.

† The molar concentration of glycerol added in each case was equal to the molar concentration of the total number of ions removed.

‡ See table 1. Incubation times: B10 and B20, 40 hr; B9, B16 and B30, 48 hr; B26, 72 hr.

TABLE 3

The ability of single salts to replace groups of salts for the growth of marine bacteria in artificial sea water medium

Composition of Artificial Sea Water*	Additions	Organism Tested					
		B9	B10	B16	B20	B26	B30
		Per cent incident light transmitted†					
Complete	—	19	6	24	26	17	17
No Na^+ salts	—	100	100	100	100	100	100
No Na^+ salts	NaCl (2.29 mM)	18	6	27	7	16	19
No Na^+ salts	Na_2SO_4 (1.145 mM)	20	16	28	100§	16	16
No Na^+ salts	KCl (2.29 mM)	100	100	100	100	100	100
No K^+ salts	—	100	100	99	97	100	97
No K^+ salts	KCl (48.6 μmoles)	18	5	23	19	16	17
No K^+ salts	KBr (48.6 μmoles)	20	4	23	26	16	17
No K^+ salts	NaCl (48.6 μmoles)	100	100	100	100	100	100
No Mg^{++}, Ca^{++}, or Sr^{++}	—	100	99	98	99	95	91
No Mg^{++}	—	100	99	96	99	68	83
No Ca^{++}	—	96	95‡	21	14	16	17
No Sr^{++}	—	19	16	23	11	16	17

* See table 2.

† See table 1. Incubation times: B20, 40 hr; B10, 48 hr; B16 and B30, 66 hr; B9 and B26, 90 hr.

‡ Growth after 90 hr, 32.

§ Growth after 120 hr, 28.

sufficiently long. Maximum growth was achieved much more rapidly in some cases, however, with NaCl than with Na_2SO_4. This was particularly noticeable in the case of B20, where maximum growth in the presence of Na_2SO_4 was not reached until after an incubation period of 120 hours. A level of KCl equal to that of the NaCl added did not permit growth of the organisms. These findings indicate that lack of growth in the absence of Na^+ salts was due primarily to a deficiency of Na^+ in the medium.

Two K^+ salts are present in artificial sea water, KCl and KBr. Growth resulted when the total K^+ provided by these two salts was made available by either one, but not when the K^+ salts were replaced by equimolar concentrations of NaCl (table 3). These results indicate that, in addition to a requirement for Na^+, all of the organisms tested need K^+.

When Mg^{++}, Ca^{++}, and Sr^{++} salts were omitted from the medium, little or no growth of any of the organisms was obtained. A deficiency of Mg^{++} alone prevented growth of four of the organisms and greatly restricted the growth of the other two. Without added Ca^{++}, B9 would not grow, while B10 grew only after a relatively long incubation period. A deficiency of Sr^{++} had no significant effect on the growth of any of the organisms. One can conclude, then, that at least four and probably all of the organisms tested have an absolute requirement for Mg^{++} for growth, while one needs Ca^{++} as well.

A salt solution was prepared[4] which provided those ions in sea water which this study has shown to be required for the growth of the six marine bacteria. Na^+, K^+, Mg^{++}, and Ca^{++} were each added to the medium at the level at which they are present in one-half concentrated artificial sea water. Growth of the bacteria in a medium prepared with this salt solution was compared with growth when half strength artificial sea water (supplemented with Fe^{++}) was used as the diluent. The results (table 4) reveal that growth in the medium prepared with the salt solution was in every case equal to or better than growth in the medium prepared with artificial sea water. A supplement of yeast extract ash was also added to tubes containing the salt solution to determine whether further growth could be obtained by supplying traces of other inorganic ions. In the case of only one organism, B16, was any ap-

[4] Composition of salt solution containing ions found to be required for growth by the marine bacteria studied: NaCl, 12.705 g/L; KCl, 0.72 g/L; $FeSO_4(NH_4)_2SO_4$, 0.0254 g/L; $MgCl_2$, 2.49 g/L; $CaCl_2$, 0.551 g/L.

TABLE 4

Comparison of the growth response of marine bacteria in media prepared with artificial sea water and with salts providing ions known to be required for growth

Diluent	Organisms Tested					
	B9	B10	B16	B20	B26	B30
	Per cent incident light transmitted*					
Artificial sea H_2O (half strength + Fe^{++} (50 μg per 10 ml)	19	12	32	32	43	18
Salt solution	20	16	31	29	16	16
Salt solution + 1 ml yeast extract ash	17	23	23	40	15	15

* See table 1. Incubation times: B20, B26, and B30, 66 hr; B9, B10, and B16, 71 hr.

preciable stimulation obtained when yeast extract ash was added.

Since phosphorus is intimately involved in the metabolism of all living forms so far examined, and as sulfur amino acids are normal constituents of proteins, one would expect that marine bacteria would require sources of both phosphorus and sulfur in the medium for growth. To test the need for a source of phosphate, a phosphate deficient medium was prepared by replacing the $(NH_4)_2HPO_4$ used to introduce phosphate into the medium with an equivalent amount of $(NH_4)_2SO_4$. None of the organisms grew to more than a very limited extent in this medium unless $(NH_4)_2HPO_4$ was added back (table 5). The addition of the same amount of NH_4^+ introduced as $(NH_4)_2SO_4$ did not permit growth, indicating that the response to $(NH_4)_2HPO_4$ was due to the phosphate it supplied. When the sulfate salts in the medium were replaced by chloride, two of the organisms, B20 and B30, grew to an appreciable extent. Even in the case of these organisms, however, the addition of K_2SO_4 to the SO_4^{--} deficient medium greatly improved growth. The results indicate that four of the organisms definitely require SO_4^{--} for growth, and two others probably require it also, although in amounts capable of being partially satisfied by contaminating traces present in the medium.

To determine if chloride was required for growth by any of the organisms, a medium was prepared using a salt mixture in which all of the chloride salts with the exception of Ca^{++}, which was added as the nitrate, were replaced by their corresponding sulfates. The yeast extract nutrient broth medium used to grow the inoculum was prepared, using this same chloride deficient salt mixture. The growth response of the organisms in the chloride deficient basal medium is recorded in table 5. In the case of only one organism, B9, was no growth obtained in this medium unless NaCl was added. For another, B20, the maximum growth achieved in the absence of chloride was significantly less than was obtained in its presence. For the other or-

TABLE 5

Some anion requirements of marine bacteria

Medium*	Additions Per 10 Ml	Organisms Tested					
		B9	B10	B16	B20	B26	B30
		Per cent incident light transmitted†					
PO_4^{---} deficient	None	98	100	100	88	95	96
	$(NH_4)_2HPO_4$ 11.3 μmoles	18	10	26	10	15	14
	$(NH_4)_2SO_4$ 11.3 μmoles	97	99	100	88	98	94
SO_4^{--} deficient	None	100	100	100	57	97	66
	K_2SO_4 66.0 μmoles	19	10	22	12	14	15
	KCl 132.0 μmoles	99	100	100	98	92	87
Cl^- deficient	None	100	40	26	69	17	29
	NaCl replacing Na_2SO_4	16	34	23	30	15	22
	2.89 mM NaCl	18	23	21	15	30	71

* The salt solution of footnote 4 was used in this medium with modifications as described in the text.

† See table 1. Incubation times: For the PO_4^{---} and SO_4^{--} experiments: B20, 24 hr; B9, B10, B16, B30, 48 hr; B26, 72 hr. For the Cl^- experiment: B20 and B30, 48 hr; B10, B16, and B26, 72 hr; B9, 96 hr.

ganisms studied, growth was either not affected or only delayed by the absence of added chloride. It was necessary to establish whether or not growth of B9 and B20 on the addition of NaCl to the Cl^- deficient medium was due to the introduction of Cl^- or to an increase in either the Na^+ concentration or the total ionic strength of the solution. Since adding further Na_2SO_4 to the medium at a level equivalent to the added NaCl would have introduced a toxic level of SO_4^{--}, Na_2SO_4 present in the basal medium was replaced by a level of NaCl providing the same amount of Na^+. Although this did not provide two solutions of exactly the same ionic strength, it did provide another medium containing Cl^- ion in which neither an increased ionic strength nor additional Na^+ could be the factor determining growth. Again, maximum growth of B9 and B20 occurred in the medium containing the chloride ion. It is thus evident that B9 requires Cl^- for growth. It would appear also that B20 has an absolute requirement for Cl^- but that the amounts needed are less than are required by B9, and can be partially provided for by contaminating traces of chloride present in the medium.

ZoBell has reported that, after laboratory cultivation on sea-water media for periods of 2 to 12 years, 56 of 60 species of marine bacteria developed the ability to grow on fresh water media (ZoBell, 1946). It would appear from this observation that marine bacteria lose comparatively readily the one characteristic which has been used to distinguish them from land forms. Since it would be of interest to know what changes in specific ion requirements would be represented by such a marked change in salt requirements, an attempt was made to train two of the marine bacteria used in this study to grow in a medium prepared with fresh water. ZoBell's observations were made using a complex laboratory medium which would be expected to supply trace elements in amounts sufficient for the growth of most terrestrial bacteria. In the training studies carried out here a medium of similar complexity was used, i.e., yeast extract, 0.5 per cent; nutrient broth, 0.8 per cent. If full strength sea water was used as the diluent in this medium, the sea water concentration was considered to be 100 per cent. Lower sea water concentrations were obtained by diluting the diluent appropriately with fresh water. Initially, the minimum concentrations of sea water in the medium supporting just visible growth of the two organisms studied were 9 and 12 per cent, respectively. After serially subculturing the organisms into media containing progressively lower concentrations of sea water, cultures were eventually obtained which could produce just visible growth at sea water concentrations of, in one case, 3.25 per cent, and in the other, 3.2 per cent. The organisms, when grown at these low concentrations, however, autolyzed very rapidly and failed to survive more than 1 or 2 subcultures into media of the same sea water concentrations. Repeated attempts to obtain growth at still lower sea water concentrations were unsuccessful.

DISCUSSION

Marine bacteria have been differentiated from land forms on the basis of their need for sea water rather than fresh water for growth in a complex laboratory medium on initial isolation. The results of this investigation reveal that, at least for the marine bacteria studied here, the requirement for sea water in the medium is based on the capacity of sea water to supply the kinds and amounts of inorganic ions required for growth by the organisms. In addition it has been observed that none of the organisms investigated here has gained the capacity to grow in a complex medium prepared with fresh water, even after 2½ years of cultivation on laboratory media. An attempt to develop such a capacity in two of the organisms by the application of training techniques was unsuccessful.

There are two unusual features of the qualitative mineral requirements of the marine bacteria revealed by this study. One is the fact that all of the organisms investigated require Na^+ for growth and two of them need Cl^-. Only one organism from a terrestrial source, the red halophile *Pseudomonas salinaria*, has been reported to require Na^+ for growth (Brown and Gibbons, 1955), although the presence of Na^+ in the medium improved the response of *Lactobacillus arabinosus* to pantothenic acid (Sirny *et al.*, 1954) and shortened the lag phase in the growth of *Clostridium perfringens* (Shankar and Bard, 1952). True marine bacteria may well prove to be distinguishable from land forms present as contaminants in sea water not by having a requirement for sea water but rather by having a readily detectable need for Na^+ in the medium for growth.

The only other report of a Cl^- requirement for the growth of bacteria is that for the halophile

P. salinaria (Brown and Gibbons, 1955). That Cl^- can be involved in the metabolism of microorganisms in capacities other than those concerned with growth, however, is apparent from the fact that two antibiotics produced by microorganisms—chlortetracycline (Broschard *et al.*, 1949) and "chloromycetin" (Ehrlich *et al.*, 1947)—contain chlorine.

Sea water does not contain sufficient iron to permit the marine bacteria investigated to grow either at their maximum rate or to the fullest extent. This, of course, applies only under the cultural conditions used in the laboratory. In their natural environment, the majority of marine bacteria are believed to be attached to the surfaces of larger organisms and to particles suspended in the sea. These surfaces, by adsorption, would be able to concentrate nutrients sufficiently to enable better growth of the marine bacteria to take place than would occur if the bacteria lived free in the sea (ZoBell, 1946).

SUMMARY

The need of six marine bacteria for sea water in a chemically defined medium has been shown to be due to the ability of sea water to supply the inorganic ions required for growth by the organisms. No evidence was obtained that sea water was capable of supplying unknown organic factors either required by or stimulatory for the growth of these organisms.

A supplement of iron in the sea water medium increased both the rate and the extent of growth of all of the organisms tested. None of the organisms grew unless Na^+ and K^+ were added to the medium. Additions of Mg^{++} were required by four of the organisms and were stimulatory for the growth of the other two. Ca^{++} was required by one organism and stimulated the early growth of another. None of the organisms grew significantly without PO_4^{---} in the medium while the absence of SO_4^{--} prevented the growth of four organisms and reduced the amount of growth of the other two. One organism required Cl^-, the growth of another was limited by its absence, while the remainder either were unaffected by its absence or needed Cl^- for optimum rate of growth. Attempts to train two of the marine bacteria studied to grow in a complex medium prepared with fresh water instead of artificial sea water were unsuccessful.

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Marine Sterols. II. 24-Methylenecholesterol in Molluscs

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A new sterol, 24-methylenecholesterol, has recently been isolated from two species of the class pelecypoda, oyster, *Ostrea virginica* and clam, *Saxidomus giganteus*.[1] From the viewpoint of the comparative biochemistry of sterols it was of interest to further investigate the occurrence of 24-methylenecholesterol in pelecypoda.

This paper reports the occurrence of 24-methylenecholesterol in three other members of the same class, scallop, *Pecten caurinus*, cockle, *Cardium corbis*, and in a commercially prepared crude sterol mixture from mussel *Modiolus demissus*.[2]

The chromatographic pattern of *p*-phenylazobenzoyl (azoyl) esters of scallop, cockle, and mussel sterols resembled that of oyster and clam. The minor top zone ($\Delta^{5,7}$-sterol) was absent, zone 1 consisted of 24-methylenecholesterol, zone 2 of a diunsaturated, and zone 3 of a monounsaturated sterol.

The identity of these bands with the corresponding bands in the chromatogram of oyster and clam sterol azoyl esters was indicated by a comparison of the infrared spectra of the free sterols.

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EXPERIMENTAL[3]

Preparation of crude sterols. Commercially packed frozen scallop muscle (6.58 kg.) was ground up with an equal weight

(1) Idler and Fagerlund, *J. Am. Chem. Soc.*, 77, 4142 (1955).

(2) Bergmann and Ottke, *J. Org. Chem.*, 14, 1085 (1949).

(3) Melting points are uncorrected. Optical rotations were measured by means of a Rudolph precision polarimeter. Infrared spectra were recorded of solid films with a Perkin-Elmer doublebeam infrared spectrophotometer.

of sodium sulfate and the mixture was shaken with two 15 l. portions of petroleum ether (b.p. 65–110°). By evaporation of the solvent 8.0 g. of fat were obtained. Further shaking with the same volume of chloroform yielded 32.8 g. (total fat 0.62%). The fat was saponified for 2 hours in 10% ethanolic potassium hydroxide and the non-saponifiable matter, 9.4 g. (23.0%) of yellow solid, was dissolved in methanol. Cooling precipitated 6.49 g. (69.0%) of sterols melting at 130–132°, recrystallized m.p. 132–133° $[\alpha]_D^{22}$ −37.7°. The addition of water to the non-saponifiables supernatant precipitated 390 mg. of sterols, m.p. 124–126°.

In the case of cockle the entire contents of the shell (278 g.) were extracted with three 1000-ml. portions of acetone; when the solvent was evaporated and the remaining water suspension was extracted with ether, 7.5 g. (2.7%) of fat were obtained. Phosphatides were precipitated by the addition of magnesium chloride to an acetone solution of the fat. Saponification for 2 hours in 10% ethanolic potassium hydroxide yielded 950 mg. (12.7%) of non-saponifiable matter. Recrystallization from methanol gave 390 mg. (41.1%) of sterols m.p. 129–131°, $[\alpha]_D^{22}$ −30.6°.

Mussel sterols were obtained by recrystallization of the commercially prepared, crude sterol mixture.[2]

Chromatography. *p*-Phenyl azobenzoyl esters of scallop, cockle and mussel sterols were chromatographed on silicic acid-Celite employing the same technique as in the case of oyster and clam.[1,4]

Scallop esters separated into three closely running bands of approximately equal intensity. There was 34.6% of 24-methylenecholesterol. Because of the relatively low concentration of zone 2 (16.7%), cockle sterols appeared to separate into only two nearly equally intense bands, but after the chromatogram had been extruded a faint band appeared between the two major components. 24-Methylenecholesterol represented 53.3% of the sterols of cockle. The distribution of the zones of scallop and mussel together with that of oyster and clam is shown in Table I.

TABLE I

DISTRIBUTION OF AZOYL ESTERS IN PELECYPODA

	Oyster, %	Clam, %		Scallop, %	Cockle, %
Zone 1	5.0	3.0			
Zone 2	36.1	53.0	Zone 1	34.6	53.3
Zone 3	28.6	21.3	Zone 2	39.4	16.7
Zone 4	30.3	22.7	Zone 3	26.0	30.0

Mussel azoyl esters also separated into three zones on the column. 24-Methylenecholesterol represented 5.4% of the total azoyl esters. Since, however, the commercial sterol mixture had previously undergone crystallization for removal of 7-dehydrosterols[2] no conclusions could be drawn about the original composition of mussel sterols.

Properties of 24-methylenecholesterol and derivatives. Zone 1 azoyl ester from scallop crystallized from benzene-aq. ethanol, m.p. 197°; mixed with azoyl ester of 24-methylenecholesterol from oyster,[1] m.p. 196°. The azoyl ester was hydrolyzed[5] and the acetate was prepared. Ultraviolet absorp-

(4) Idler and Baumann, *J. Biol. Chem.*, 195, 623 (1952).

(5) Idler, Nicksic, Johnson, Meloche, Schuette, and Baumann, *J. Am. Chem. Soc.*, 75, 1712 (1953).

tion and the modified Liebermann-Burchard reaction[6,7] of the crude acetate showed the presence of 2.6% of $\Delta^{5,7}$ sterols (calc'd as ergosterol) which were removed with maleic anhydride in the usual manner.[1] The recrystallized acetate of zone 1 melted at 136°, mixture m.p. 136° with 24-methylenecholesterol, $[\alpha]_D^{22}$ −42.9°.

Anal. Calc'd for $C_{30}H_{48}O_2$: C, 81.76; H, 10.98. Found: C, 81.71; H, 10.88.

The *acetate* was hydrolyzed and the *sterol* was crystallized from methanol, m.p. 141°, mixture m.p. 141° with 24-methylenecholesterol, $[\alpha]_D^{22}$ −35.7°.

The *benzoate* melted at 147°, undepressed on admixture with 24-methylenecholesterol benzoate, $[\alpha]_D^{22}$ −14.2°.

24-Ketocholesteryl acetate and derivatives. The acetate of zone 1 in cold glacial acetic acid-acetic anhydride (1:1) was treated with 2 equivalents of ozone. The ozonolysis product was worked up as previously described.[1] Subsequent crystallization from methanol yielded a substance with the m.p. 127°, $[\alpha]_D^{22}$ −43.1°. Mixture m.p. with 24-ketocholesterol from oyster and a synthetic product was 127°. *24-Ketocholesterol acetate oxime* was prepared by refluxing with hydroxylamine hydrochloride in pyridine-ethanol. Two recrystallizations from aq. ethanol gave m.p. 169°, mixture m.p. 169° with the synthetic material.

Anal. Calc'd for $C_{29}H_{47}NO_3$: C, 76.10; H, 10.35; N, 3.06. Found: C, 76.34; H, 10.56; N, 2.94.

24-Ketocholesterol acetate 2,4-dinitrophenylhydrazone was recrystallized from ethanol. M.p. 169°, mixture m.p. 169° with the synthetic product.

Anal. Calc'd for $C_{35}H_{50}N_4O_6$: C, 67.50; H, 8.09. Found: C, 67.38; H, 8.22.

24-Methylenecholesterol from cockle and mussel. 24-Methylenecholesterol and derivatives were prepared from zone 1 of cockle and mussel identically as described above for scallop. The preparations contained only insignificant quantities of Δ^7-sterols. The properties of the sterol and of the azoyl ester, acetate, and benzoate were identical with those of 24-methylenecholesterol from oyster, clam, and scallop.

Infrared spectra. The identify of 24-methylenecholesterol from the five sources so far investigated was confirmed by a comparison in detail of their infrared spectra. The spectrum of 24-methylenecholesterol showed the maxima at 890 and 1640 cm^{-1} characteristic of the methylene group.[1] Other changes in the spectrum caused by introduction of the 24 (28) double bond were a sharp (weak) peak at 3050 cm^{-1} and a broader (weak) band at 1750–1790 cm^{-1}. These data were derived from a comparison of the spectrum of 24-methylenecholesterol with those of its neutral reduction product (Adams' catalyst in ethyl acetate) and of campesterol.

The infrared spectra of zone 2 from scallop, cockle, and mussel and the diunsaturated zone 3 from oyster and clam were compared and found to be identical. The second double bond does not introduce any major bands. A comparison with the spectra of Δ^5-sterols showed the following characteristics: Absence of the weak band at 925 cm^{-1}; a dominant shoulder at 965–975 cm^{-1}; absence of the weak peak at 1240 cm^{-1}; shifting of the weak band at 1305 cm^{-1} to 1295 cm^{-1}; absence of the shoulder at 1360 cm^{-1}. The monounsaturated bottom zone from oyster, clam, scallop,

(6) Idler and Baumann, *J. Biol. Chem.*, **195**, 615 (1952).
(7) Idler and Baumann, *J. Biol. Chem.*, **203**, 389 (1953).

cockel, and mussel produced a spectrum typical of Δ^5-sterols. The clam and scallop sterol has been reduced to a stanol with Adams' catalyst in glacial acetic acid but the product and its derivatives do not possess the properties of any previously described unsaturated sterol.

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Sodium and Potassium in Fish from the Canadian Pacific Coast[1]

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SODIUM-restricted diets are widely used in the dietary management of a number of diseases (1, 2). To devise varied and nutritionally adequate low-sodium diets, dietitians require reliable estimates of the sodium content of foods. The Food and Nutrition Board of the United States has listed, by reference, nearly a thousand analyses encompassing hundreds of foods (1). From this list, a table has been prepared called "Estimated Best Values of the Sodium Content of Foods." As indicated in the report and stressed by Clifford (3), such estimates represent only an "educated guess," and much more work must be done before such figures can be accepted with good confidence. The values for the sodium content of fish have been recorded for only a limited number of genera, and no attempt has been made to determine the extent of species variation.

The present study was undertaken to determine the sodium and potassium content of fish caught in commercial quantities along the northwest Pacific Coast. The results obtained are listed according to species. Certain variations within species due to size and season of catch are also recorded.

[1] Received for publication February 6, 1956.

[2] The authors take pleasure in acknowledging the fact that J. F. Murray assisted in various capacities throughout this work, and that Charles Brumwell aided in the analyses in the earlier stages of the study.

Experimental Procedure

All fish were obtained either from a wholesaler or directly from fishing boats. The fish were cleaned and then sampled according to a slight modification of the official A.O.A.C. method (4). Three slices were removed from each fish, one from behind the head, one from the mid-section, and one from just in front of the tail. After removing the skin and bones, flesh from the three slices was pooled and homogenized. The method of preparing samples for analysis was similar to that described by Wallace *et al.* (5). Five-gm. samples of the homogenized fish were placed in Erlenmeyer flasks, and 3 ml. of reagent grade concentrated nitric acid were added. The samples were heated gently with constant agitation until evenly dispersed. The mixture was cooled, transferred to a 100-ml. volumetric flask, and diluted to volume with a solution containing 20 per cent ethanol in distilled water. The solution was filtered, and aliquots were diluted with sufficient 20 per cent ethanol to bring the samples within the range of sodium or potassium concentration required for use with the flame photometer. Ethanol was incorporated into the diluent to increase the sensitivity of the flame photometer to sodium and potassium (6).

All analyses were made using a flame photometer attachment for a Beckman DU spectrophotometer equipped with a photomultiplier. Most of the determinations were made with an oxy-acetylene burner, though more recently an oxy-hydrogen flame has been used. Preliminary studies established that calcium and potassium at the approximate levels present in fish did not affect the response of the flame photometer to sodium at the dilutions tested. Similarly, the sodium and calcium levels did not alter the response to potassium. The spectral line selected for the determination of sodium was 589 mμ and for potassium, 768 mμ.

Sodium and potassium standards were prepared by dissolving the respective reagent grade chloride salts in a solution of 20 per cent ethanol in distilled water. The recommended technique for determining the sodium or potassium content of a solution by comparison of its emission intensity with standards of slightly higher and lower concentration was used (7).

Results

The levels of sodium and potassium in the flesh of red spring salmon caught at monthly intervals

over a five-month period are shown in Table 1. It can be seen that from May to June there was a small drop and from June to July a very sharp drop in the sodium content of the flesh of fish of the same size range. The low sodium level attained in July was maintained in August. As the sodium content of the flesh went down, the potassium level tended to rise.

Not only was there a variation in the sodium content of fish of the same size caught at different times, but also with fish of differing size caught at the same time. Small red spring salmon caught in May had a significantly higher sodium content than medium or large red spring salmon caught in the same month (Table 1). In the case of this type of variation, however, the lower sodium level of larger fish was not counterbalanced by a higher potassium content. No significant difference in the amount of sodium and potassium in the flesh of red and white spring salmon of the same size range is apparent from the table.

TABLE 1

*Sodium and potassium content of spring salmon**

SIZE†	MONTH CAUGHT	NUMBER OF FISH ANALYZED	SODIUM		POTASSIUM	
			Average	Range	Average	Range
Red Spring Salmon‡			*mg./100 gm.*	*mg./100 gm.*	*mg./100 gm*	*mg./100 gm.*
Small	April	9	55.7	53.5–58.0	352	330–395
Small	May	24	57.7	50.5–61.5	408	375–445
Small	June	3	51.4	49.2–54.2	408	395–430
Small	July	6	37.5	35.0–40.0	418	417–420
Small	August	7	39.5	35.2–45.0	447	410–470
Medium	May	11	39.4	32.0–47.5	376	350–408
Large	May	15	38.2	31.0–45.0	371	320–408
White Spring Salmon						
Medium	June	2	37.3	33.0–41.5	409	408–410

* Other common names for this species are: king, chinook, and quinnat.

† Small, 2 to 7 lb.; medium, 7 to 20 lb.; large, 20 to 40 lb.

‡ *Oncorhynchus tshawytscha.*

The sodium and potassium content of the flesh of four other species of salmon is shown in Table 2. In the Coho salmon, the variation in sodium content appears to occur with both size and season. This variation of size within a species is considerably more marked than that occurring from one species to another. The widest variation in sodium and potassium content within a species was that observed in Sockeye salmon, though all of the fish analyzed were quite uniform in size.

Values for various other commercially important fish are listed in Table 3. It can be seen that the tendency observed in salmon for the flesh of larger fish within a species to contain less sodium than smaller ones did not extend to lingcod or halibut. In the case of halibut, fish of medium size actually contained, on the average, slightly more sodium than those in the small size range.

Herring showed little variation in sodium content between September and January. This lack of variation with season contrasts with the change in the sodium content of spring salmon with time.

Discussion

The results reported here indicate that in salmon, more variations in sodium and potassium content may occur within any one species than between various species in the genus. These variations appear to be related, at least in some species, to the size of the fish and the season when the fish are caught. It also appears that the same relationships do not hold for the other genera investigated, since the sodium and potassium content of lingcod and halibut did not vary with size in the same way as salmon, and herring maintained a quite uniform sodium content over a five-month period.

It is interesting to speculate on the reasons why there appears to be this generic difference in variation of sodium content with size and season. The salmon, which do vary, spend a portion of their life-cycle in fresh water, while the other genera live their entire lives in the sea. It is possible that the

variations in sodium content noted in the salmon may be related in some way to the period in their life cycle in which they were caught; for instance, to the nearness of the approach of the fish to the time of their spawning migration. Much further work, of course, remains to be done to establish any such relationship.

The estimated best values for various species of fish reported by the Food and Nutrition Board (1) include the following sodium values (in milligrams per 100 gm. flesh): salmon, 50; halibut, 56; herring, 100; and codfish, 65. Only the estimated best value for halibut agrees well with those reported here. Our results indicate that the value for a given species of salmon can differ from the estimated best value by as much as 25 per cent, depending on the factors mentioned earlier. In the case of herring, the estimated best value is about 33 per cent higher than the average obtained in this study, where thirty-one different fish were analyzed.

Summary

The sodium and potassium levels in the flesh of lingcod, graycod, halibut, herring, brill, lemon sole, and five species of salmon (genus *Oncorhynchus*) caught along the Pacific Coast of Canada are reported. In salmon, more variation in the sodium and potassium content occurred within a species than between species. The sodium concentration in the flesh of spring and Coho salmon weighing 7 to 40 lb. was 25 to 30 per cent less than that in the same species caught at the same time weighing 2 to 7 lb. The flesh of spring salmon caught in July and August contained up to 30 per cent less sodium than that from fish of the same species and size range caught in April and May. In the case of lingcod and halibut, little variation in sodium and potassium content with size was observed, and with herring no significant change was recorded in sodium and potassium content over a five-month period. It is suggested that the change in sodium and potassium content of salmon may be related to the fact that part of their life cycle is spent in fresh water. Some comparisons are made between the sodium and potassium values recorded in this study and the estimated best values reported by the United States' Food and Nutrition Board (1).

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TABLE 2

*Sodium and potassium content of fresh Coho, Sockeye, Chum, and Pink salmon**

SPECIES	SIZE†	MONTH CAUGHT	NUMBER OF FISH ANALYZED	SODIUM		POTASSIUM	
				Average	Range	Average	Range
				mg./100 gm.	*mg./100 gm.*	*mg./100 gm.*	*mg./100 gm.*
Coho salmon (*Oncorhynchus kisutch*)	small	June	9	54.3	51.5–57.5	428	420–440
Coho salmon (*Oncorhynchus kisutch*)	small	July	10	50.8	42.0–57.5	409	385–450
Coho salmon (*Oncorhynchus kisutch*)	medium	July	21	39.7	33.0–45.9	427	420–440
Sockeye salmon (*Oncorhynchus nerka*)	small	July	42	47.5	39.2–60.0	391	340–453
Pink salmon (*Oncorhynchus gorbuscha*)	small	August	6	56.1	48.0–70.0	443	410–485
Chum salmon (*Oncorhynchus keta*)	medium	November	6	49.7	47.9–54.3	429	404–440

* Coho salmon are also referred to as silver salmon; Sockeye, as red or blueback; Pink, as humpback; and Chum, as dog salmon.

† Small, 2 to 7 lb.; medium, 7 to 20 lb.

TABLE 3

Sodium and potassium content of fish of various genera

SPECIES	SIZE*	MONTH CAUGHT	NUMBER OF FISH ANALYZED	SODIUM		POTASSIUM	
				Average	Range	Average	Range
				mg./100 gm.	*mg./100 gm.*	*mg./100 gm.*	*mg./100 gm.*
Lingcod (*Ophiodon elongatus*)	small	May	12	54.9	48.0–67.2	418	380–460
Lingcod (*Ophiodon elongatus*)	medium	May	6	51.8	49.5–54.1	478	475–480
Graycod (*Gadus macrocephalus*)	small	May	16	71.2	60.5–83.5	392	340–432
Halibut (*Hippoglossus stenolepsis*)	small	May	28	58.9	51.0–64.0	452	420–485
Halibut (*Hippoglossus stenolepsis*)	medium	May	9	62.0	49.5–70.0	475	435–510
Herring (*Clupea pallasii*)	†	September	9	74.0	73.0–74.5	367	355–380
Herring (*Clupea pallasii*)	†	November	10	75.6	70.0–83.0	451	425–470
Herring (*Clupea pallasii*)	†	January	12	72.2	66.0–77.9	441	405–472
Brill (*Eopsetta jordani*)	small	November	6	85.2	82.5–87.0	402	390–416
Lemon sole (*Parophrys vetulus*)	small	November	6	87.1	85.6–88.2	402	395–416

* Small, 2 to 7 lb.; medium, 7 to 20 lb.; large, 20 to 40 lb. † The average weight of the herring was 4 to 5 oz.

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EFFICIENCY OF YEAR-ROUND OPERATION OF TROUT COUNTING FENCES ON A SMALL STREAM

by

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Two counting fences of a type often employed in studies of populations of anadromous fish have been maintained for a number of years on Ellerslie Brook, Prince Edward Island. The effect of building a dam and forming a pond on the trout (*Salvelinus fontinalis*) population of this stream is being studied (Smith, 1951a, 1951b). Since the trout are tagged at Ellerslie Brook, and many are recaptured, there has been the opportunity to assess the efficiency of the counting fences. Operators of counting fences infrequently have had this opportunity.

The counting fences are maintained throughout the year on Ellerslie Brook. They are tended daily. All trout captured at the fences are tagged, as well as those of age I and older taken during annual population assessments in several sections of the stream. A numbered monel-metal strap tag, in circular form, is fastened around the mandible of each trout. The fork length in centimetres of all trout is recorded.

Large numbers of tagged trout have been recaptured. Records of recapture are obtained at the counting fences, from a creel census taken during the angling season of each year, during population studies in the stream, and by the commercial operations of smelt nets in the estuary of Ellerslie Brook. Accordingly, it has been possible to learn how many of the recaptured tagged trout were able to pass the counting fences undetected in their upstream and downstream movements. The extent to which this occurred and reasons for failure of the counting fences to capture all trout are discussed here. Data on these points are presented for the period from April 22, 1947, to September 30, 1951. Data on trout tagged after the latter date were not considered. Trout then tagged could still be in the population and subject to further recapture.

Ellerslie Brook

Ellerslie Brook is tributary to Malpeque Bay on the north shore of Prince Edward Island (Figure 1). It is a small spring-fed stream, which, with its tributaries, has an approximate length of six miles. The brook drains an area of farms and woodlots of about 10 square miles.

Records of the volume of water flowing from Ellerslie Brook became available after a dam was built and a pond formed in 1952. A chart presented by Anderson (1937) was used to estimate the volume of water discharged through the spillways of the dam. Daily observations were made and the data for 1953 and 1954 plotted in

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Figure 2. These do not coincide in time with the data that are presented herein on the movements of tagged trout (1947-1951). However, they illustrate the range in flow of water that was probably encountered in the earlier years.

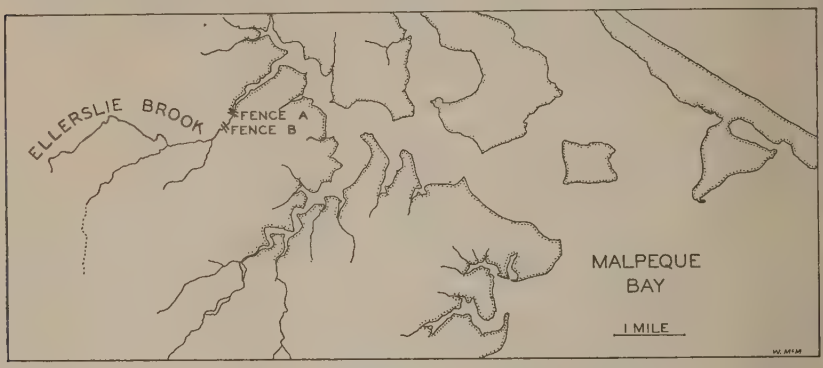


Figure 1. Map of the Ellerslie Brook area, Prince Edward Island

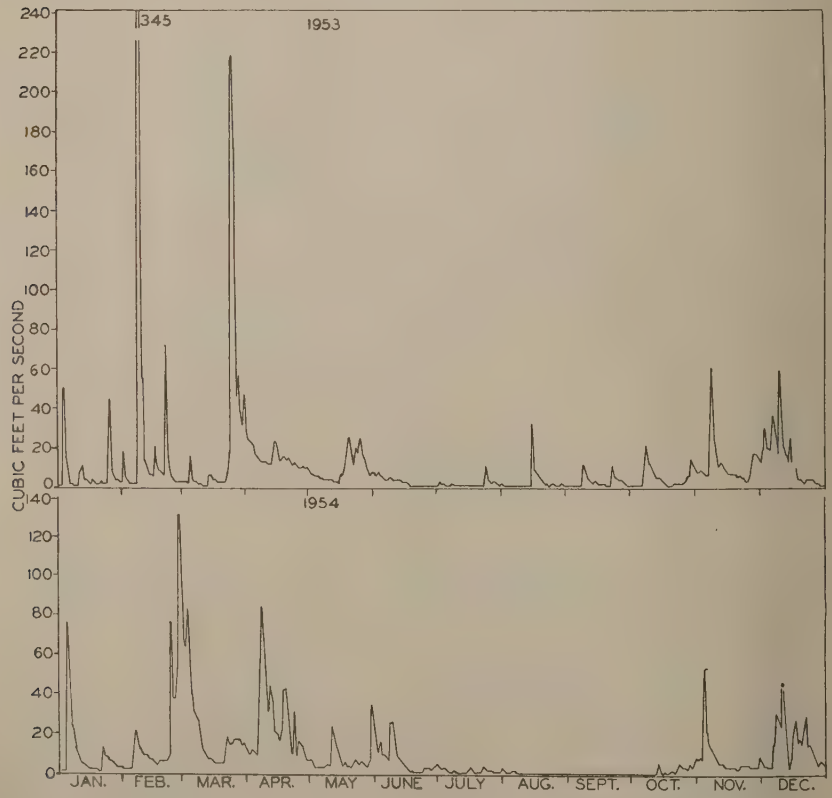


Figure 2. Volume of water discharged from Ellerslie Brook in 1953 and 1954.

The brook is subject to quite severe spates, but since the drainage basin is small they are usually of short duration. In our experience, the high flow of 345 cubic feet of water per second which was encountered on February 8, 1953, represents an extreme condition. Only on August 14, 1948, was a comparably heavy flood observed.

Ellerslie Brook Counting Fences

The counting fences capture trout as they move either upstream or down. They consist of a barrier and two traps, one to capture trout moving downstream, the other as they move upstream. The counting fences are illustrated in Figure 3. Except for minor modifications to meet conditions in Ellerslie Brook, the fences are of a design described and figured by White (1939).

Location.

Since June, 1946, a counting fence, designated A, has been maintained at the mouth of Ellerslie Brook, approximately midway between low-and high-tide levels, to observe the movements of trout between the stream and estuary. In September, 1950, a similar fence, designated B, was installed 650 yards upstream immediately above a proposed pond site. Information has been obtained from the latter fence on the movements of trout, at first within the stream and later between the stream and the pond.

Traps.

The traps at the two fences are identical. Wood is used throughout with the exception of steel rods, one-quarter-inch diameter, spaced three-eighths of an inch around the lower three feet of the traps. To minimize possible injury of trout in the traps during spates, the upper parts are constructed of closely-fitting boards rather than of spaced steel rods. Each trap is five feet wide, nine feet long and six feet high with an entrance at one end 19 inches wide and 27 inches high. A funnel is attached to this opening and extends five feet into the trap. The funnel is six inches wide at its terminal end, with a seven-inch space between its lower edge and the floor of the trap. The top and bottom of the funnel are made of boards, and the sides are wood laths spaced three-eighths of an inch.

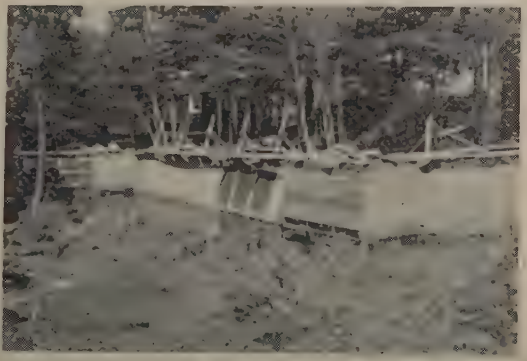
Each trap rests on a wooden platform which extends out three feet from the end and side of the trap exposed to the full force of the stream current. These extensions of the platform slope downwards. The pressure of water on these sloping surfaces aids in holding the trap in position. This type of construction lessens danger of washouts under the traps. Attendants enter the trap through a hatch on the roof to remove impounded trout. Stones are placed on the top of the trap for ballast.

Barriers.

The barriers are made up in panels of two sizes: four feet wide by six feet high, and four feet wide by three feet high. The smaller panels are placed in pairs, one above the other, at points where excessive stresses are likely to occur. The top panels can be removed if water pressure becomes too severe. On the original panels water

A. Fence A in summer

B. Fence A in winter.



C. Fence B in summer

D. Fence B in winter with frazil ice formation.

Figure 3. Ellerslie counting fences.

was strained through wood laths spaced three-eighths of an inch. To a large extent these have been replaced by one-quarter-inch diameter steel rods. These are stronger than the laths and provide a more efficient straining surface.

Difficulties Encountered in Operating Counting Fences

Storm tides.

On two occasions in the fall of 1947, once in the winter of 1951 and again in the winter of 1954 storm tides went over counting fence A. No damage to the counting fence resulted.

Freshets.

The water-straining capacity of counting fence A is approximately double that for B. (The total length of fence A is about 175 feet, and of B, 85 feet.) In consequence, less trouble has been experienced with freshets at the former. Counting fence A has effectively strained as much as 200 cubic feet of water per second but has broken down when subjected to 345 cubic feet. Counting fence B has strained in excess of 70 cubic feet of water per second but became inoperative on November 4, 1954, when a freshet of 60 cubic feet per second caused an accumulation of leaves on the barriers. Almost all of the breakdowns that occurred in the fences during freshets were the result of the accumulation of either ice or leaves on the screening panels. High water in itself has presented only minor difficulties in the operation of the counting fences. Attendants had to be constantly on the alert during freshets to see that the barriers were straining water properly.

Snow.

Snow on the barriers was undesirable since usually it resulted in the formation of slush that blocked the screening panels. The areas around the counting fences were protected considerably from drifting snow by snow-fences. Additional protection was had from buildings and trees. The snow was usually removed from the area immediately in the front and the rear of the fences (Figure 3B).

Ice.

(*a*) Surface ice. Much of counting fence A is located in shallow water that freezes down to the stream bed. After the first ice of the winter had been chopped away from the barriers no further difficulties were experienced. At counting fence B the depth of water is greater than at A. Here the ice was chopped away only with the onset of mild weather and possibility of freshets.

Three methods have been employed to prevent the formation of ice within the traps: (1) The traps were covered inside and out with tar paper, with a four-inch air space left between the two layers for insulation. (2) Snow was banked on occasion against the outside of each trap when the brook was frozen over. (3) During extreme cold each trap was heated by a small gravity-feed oil heater on a floating metal pan. The pan was kept level, as it adjusted to changing water levels in the trap, by guide wires that passed through rings on each corner of the pan and were fastened to the floor and roof of the trap. Only rarely was it found necessary to resort to heating.

If high water levels occurred during the annual spring breakup a few of the small panels were removed from the barrier and the broken ice was pushed through the fence.

(*b*) Frazil ice. Frazil is a fine spicular ice which may appear in a stream when the water is slightly supercooled, but is flowing too rapidly for a surface sheet to form (Barnes, 1928). It quickly agglomerates in coming in contact with solid objects, such as the counting fences in Ellerslie Brook. This phenomenon occurred in Ellerslie Brook in late fall and early spring. On numerous occasions a solid sheet of ice has been observed to form on the barriers within two hours after the first appearance of ice crystals in the water (Figure 3D). This resulted in the complete stoppage of water at the barriers and panels had to be removed to prevent the fences from being damaged.

Debris.

Debris on the screening panels slows down or stops the flow of water through the fences. Fallen leaves in the fall have been especially troublesome in this respect, particularly at counting fence B. Leaves have caused difficulties even at relatively low water levels. Raking the screening panels has proved effective, although at times involving much effort, for the removal of leaves and other small debris; large objects were either lifted over the fences or pushed through after panels had been removed.

Muskrats.

Muskrats have entered the traps through the funnels, especially in the fall and spring, and have on occasions gnawed holes through the laths on the bottoms of the traps in their attempts to escape. The trouble was minimized by replacing the laths with steel rods in 1950. They have occasionally, however, made holes through the wood panels on the barriers.

General Movements of Trout Through Counting Fences

Numbers of trout captured in traps.

The movements of trout, both tagged and untagged, through the two counting fences are shown in Table I in relation to years. It is from the recapture of the tagged trout that the effectiveness of the counting fences can be gauged. As noted, recapture was possible in the traps, by angling, during population studies and in smelt nets. Most recaptures were made in the traps and by angling. The data in Table I illustrate that a large number of the trout taken in the traps, especially the down traps, were untagged. These were being captured for the first time. However, these trout were tagged after their entry into the traps and provided data for this study by their subsequent movements.

Time of year.

Movements of trout at counting fence A in relation to season have been presented for the years 1946 through 1949 in progress reports (Smith, 1948, 1951a). Movements in 1950 and 1951 have followed the same general pattern at both counting fences. The prominent upstream movements of trout occurred in April, from mid-June to mid-July, and from mid-September to early January. Downstream movements have been most

Table I

The movements of trout through the Ellerslie counting fences.

Year	Counting fence A		Counting fence B*	
	Up	Down	Up	Down
1947 (April 1-December 31)	2491	1164	—	—
1948	1119	1747	—	—
1949	2320	3077	—	—
1950	1403	1427	—	—
1950 (September 26-December 31)	—	—	235	1424
1951 (January 1-September 30)	459	591	569	823
Totals	7792	8006	804	2247
Movements by tagged trout	4961	4163	706	698
Movements by untagged trout (first capture)	2831	3843	98	1549

* Counting fence B installed in September, 1950.

pronounced in May and from September to January. Within these several periods both upstream and downstream movements have varied from year to year in respect to the number of trout, date of occurrence and duration of the run. Few trout moved through the fences during the dead of winter or the height of summer.

Undetected Movements of Tagged Trout Through the Counting Fences

Extent of undetected movements.

There was a total of 10,528 movements by tagged trout through the counting fences after April 22, 1947, (when tagging of trout began) to September 30, 1951. This total includes those movements that were not detected, as shown by subsequent recaptures on the wrong side of the fences. There were 2,335 such undetected movements. They represented an error of 22 per cent in the trapping operations. It is assumed, without confirming evidence, that there was a comparable error in capturing untagged trout of the same length range.

This average error is minimal.

If any of the tagged trout made two or any even number of successive undetected movements through the fences, the error in trapping operations would be greater than that recorded. A correction to account for such movements would be difficult to determine since neither the movements of the trout nor the breaks in the fences occurred in a regular fashion. The tagged trout are subject to recapture at two counting fences, by anglers, in smelt nets and during population estimates in the stream. The likelihood of successive undetected movements is small. The actual undetected movements were somewhat greater than 22 per cent of the total known to have occurred, but probably not appreciably so.

In Table II the total number of movements by tagged trout and the number and percentage of those that were undetected are set forth in relation to the place and year of tagging and to the trap through which the escapement occurred. An examination of the data in Table II shows that the percentage of undetected movements through the fences, either up or down, varied markedly in respect to years and places of tagging. Such variation was not unexpected. There was no regularity—weather and rainfall were much involved—in the extent or time of the malfunctions of the fences.

Table II

Total and undetected movements by tagged trout through the Ellerslie counting fences

Place tagged and year	Total number of movements				Number of undetected movements with percentage in brackets			
	Fence A		Fence B		Fence A		Fence B	
	Up	Down	Up	Down	Up	Down	Up	Down
Fence A up—								
1947	320	633	0	0	49(15)	177(28)	0	0
1948	152	278	1	1	29(19)	54(19)	0	0
1949	148	336	2	6	12(8)	67(20)	0	0
1950	56	151	34	56	8(14)	25(17)	3(11)	2(3)
1951	20	51	89	24	4(20)	14(27)	14(18)	6(25)
Totals	696	1,449	126	87	102(15)	337(23)	17(13)	8(9)
Fence A down—								
1947	529	164	0	0	127(24)	36(22)	0	0
1948	1,050	453	1	2	319(30)	59(12)	0	0
1949	1,465	449	8	14	209(14)	107(24)	0	0
1950	335	47	25	30	64(19)	6(13)	5(20)	4(13)
1951	72	14	27	6	40(56)	7(50)	2(7)	2(33)
Totals	3,451	1,127	61	52	759(22)	215(19)	7(11)	6(11)
Fence B up—								
1950	5	24	5	54	4(80)	0	0	6(11)
1951	16	27	7	44	2(13)	12(44)	1(14)	23(52)
Totals	21	51	12	98	6(29)	12(24)	1(8)	29(30)
Fence B down—								
1950	301	704	213	80	158(53)	44(6)	19(9)	23(29)
1951	110	181	161	39	41(37)	45(25)	23(14)	20(51)
Totals	411	885	374	119	199(48)	89(10)	42(11)	43(36)
Stream—								
1948	139	239	1	2	37(27)	47(20)	0	1(50)
1949	79	152	3	15	5(6)	58(38)	0	0
1950	40	88	34	121	20(50)	13(17)	3(9)	6(5)
1951	124	172	95	204	4(3)	105(61)	5(5)	159(78)
Totals	382	651	133	342	66(17)	223(34)	8(6)	166(44)
Grand totals	4,961	4,163	706	698	1,132(23)	876(21)	75(11)	252(36)

Relation to failures of counting fences.

Dates on which the counting fences could have failed to capture all or any of the moving trout and the reasons for these failures are shown in Table III. Dates on which trout were probably moving or not moving are indicated in this table. The

Table III

Dates on which counting fences on Ellerslie Brook could have failed to capture trout and reasons for failure

Dates on which trout were probably running	Dates on which trout were probably not running
I. Counting fence (A) at mouth of brook	
(a) Storm tides	
1947 : October 13, November 18	1951 : January 8
	1954 : January 12
(b) High water during freshets	
1951 : January 5-9, May 30-June 8	1948 : August 14-16
: April 11-17	1953: February 8-March 13
(c) Frazil ice formation	
1949 : November 25, December 15, 24, 29	1949 : January 7-9
1950 : January 27 March 30, April 14, 16, 20	1950 : April 1, 2, 7
	1954 : December 23
(d) Muskrat damage	
1948 : April 28, 30, December 2	1949 : April 19
1949 : April 24, 25, 28, May 4, June 23, July 3, October 26	
II. Counting fence (B) on brook at head of pond	
(a) High water during freshets	
1950 : November 19	1953 : February 8-12, December 7, 10
1951 : January 5-9, April 10-12, May 30, November 4	1954 : February 27, December 10-11
1953 : November 8	
1954 : November 4	
(b) Frazil ice formation	
1951 : November 26-December 1	1952 : March 25-28, April 2, 10, 12, 13
1952 : April 16-18	1953 : February 10, 11, 22, March 25, December 17-19
	1954 : March 6-8, April 4-15, December 23-28

basis of separation was whether or not trout were captured in the traps immediately before, during or immediately after the interruptions in the normal operation of the counting fences.

A good number of the failures of the fences to function properly occurred in the spring and fall when the major movements of trout, both upstream and down, also occurred. Periods when the fences were inoperative and the trout could have passed undetected were short for the most part. However, if a prominent movement of

trout and a break in the fences coincided, very considerable numbers of trout could pass unobserved in a short period. Probable instances of this character are illustrated in Figure 4.

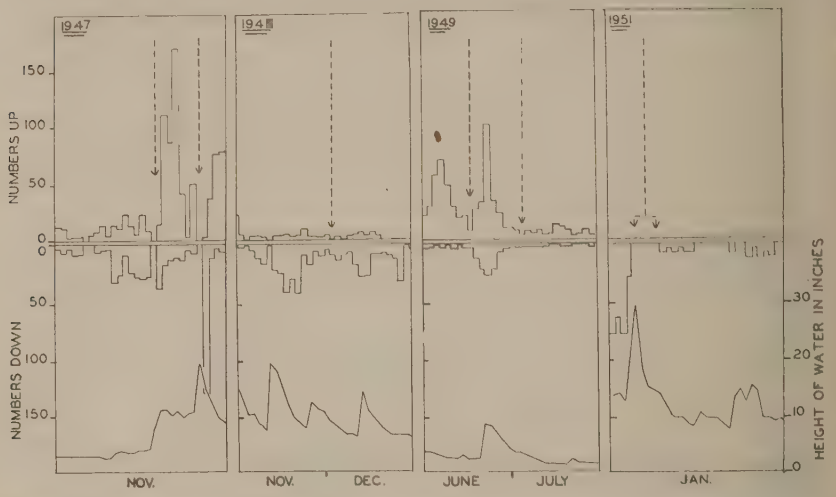


Figure 4. Recorded movements of trout at counting fence A in relation to malfunctions (indicated by arrows) of fence. 1947—Storm tide and freshet; 1948 and 1949—Muskrat damage; 1951—freshet.

In relation to length of trout.

The counting fences were not designed to capture trout fingerlings or small yearlings. Trout to about 11 centimetres (4 inches) fork length could pass through the spaces of three-eighths of an inch between the rods and laths on the barriers and traps. However, most trout over 10 centimetres in length would pass only with difficulty.

Undoubtedly small unmarked trout passed undetected between the rods and laths on the fences. It was impossible, however, to estimate their numbers. We have no evidence that, except for the occasional individual, trout fingerlings and small yearlings ran into salt water. The traps in fence A were lined with fine-mesh screening during part of the fall of 1948, until high water necessitated its removal. No trout below the lengths of those that were normally taken in these traps were captured. However, a different situation obtained at fence B. There movement through the fence only meant passing from one part of the stream to another. Possibly the greatest escapement of small unmarked trout, at times other than when breaks occurred, was through fence B.

In relation to the total movements by tagged trout through the fences, the highest percentage of those made undetected was by 12- to 13-centimetre trout (Figure 5). It was possible that some of the undetected trout in this length range passed through the three-eighths-inch spaces on the screening panels. We believe, however, that most of the undetected movements by the smaller tagged trout were through breaks in the fences. The greater proportion of the small trout moved in the fall-winter

and spring periods (Figures 6 and 7). It was during these seasons that breaks occurred most frequently in the counting fences (Table III). In contrast, the greater proportion of the larger tagged trout, among which there was a lower percentage of undetected movements, moved in late spring and early summer. This was a period of few breaks in the fences.

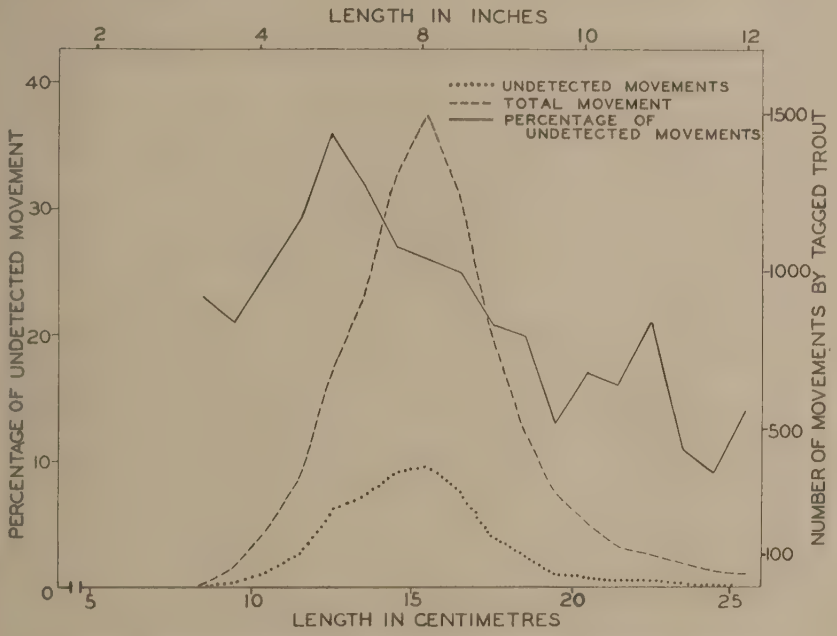


Figure 5. Relation between length of tagged trout and percentage of undetected movements.

Discussion

The extent to which trout moved undetected through the Ellerslie Brook counting fences is primarily of local interest. The data permit reasonably good corrections in arriving at the total number of trout of catchable size that moved upstream or down. However, more general interest may be attached to the fact that considerable escapement was encountered. Tagging of the trout permitted us to assess the escapement; this is usually not possible with trapping operations.

Our results were obtained on a small stream with the counting fences under close supervision. Year-round operation of counting fences on larger streams would incur increasing effort and difficulties, to the point where it would probably not be feasible.

Summary

Tagging of brook trout and their recapture showed that undetected movements through two counting fences held on Ellerslie Brook a small Prince Edward Island stream, comprised 22 per cent of the total made by tagged trout over a five-year period.

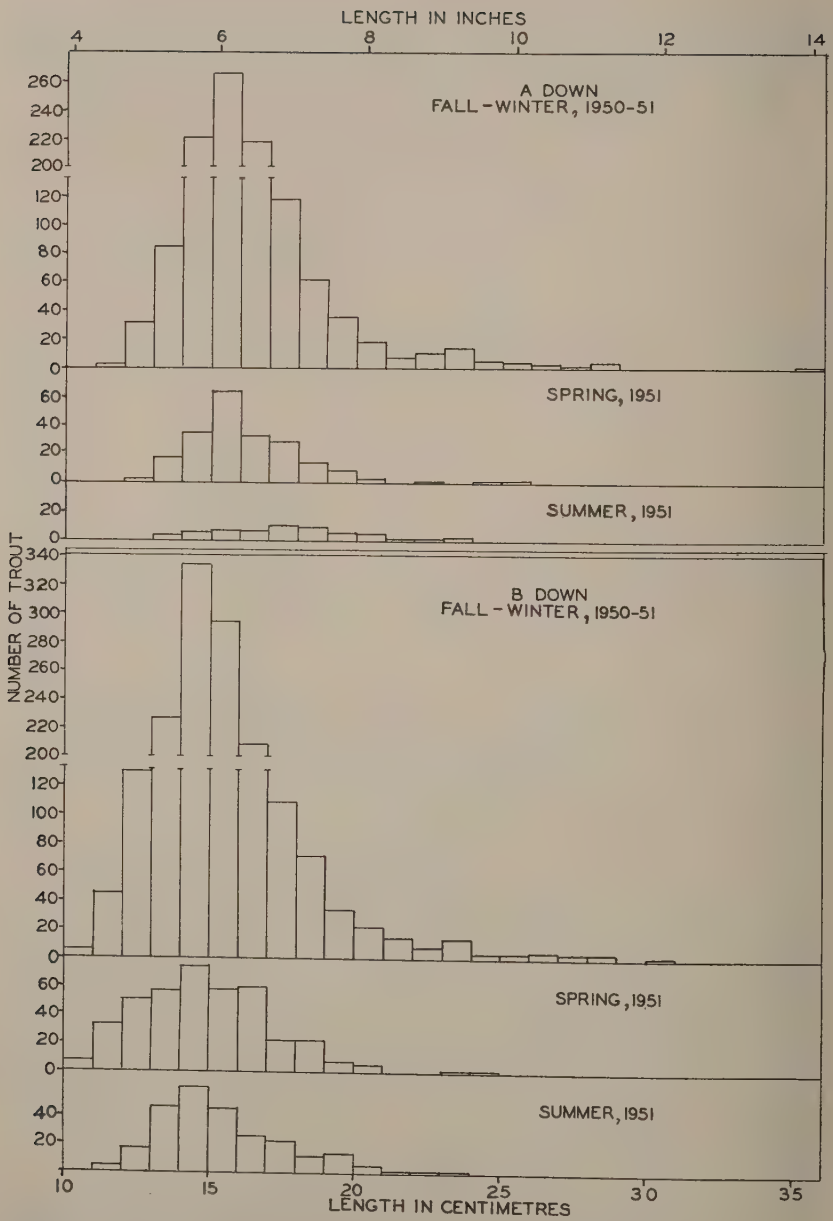


Figure 6. Length frequencies of tagged and untagged trout captured at counting fences when moving upstream.

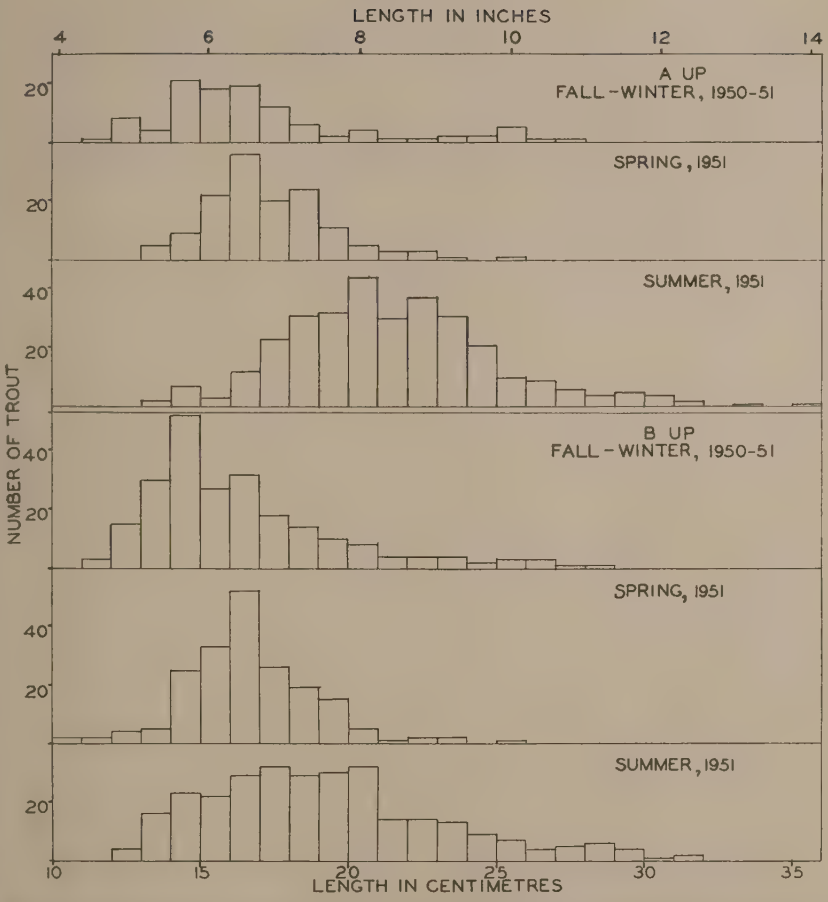


Figure 7. Length frequencies of tagged and untagged trout captured at counting fences when moving downstream.

The percentage of undetected movements varied irregularly in relation to season, year, fence and direction of movement. Freshets, accompanied by debris, frazil ice, storm tides and muskrats gave trouble in maintaining the fences in effective operation throughout the year.

Acknowledgments

Assistance in the field of C. R. Hayes and Cyril Williams and in the laboratory of Miss Mary Holmes is gratefully acknowledged. This paper is published with permission of the Fisheries Research Board of Canada.

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EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1956

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THE OCCURRENCE OF THE TWO-RONGED HATCHETFISH, *ARGYROPELE-CUS SLADENI*, IN BRITISH COLUMBIA.—A specimen of *Argyropelecus sladeni* was taken in a shrimp trawl at a depth of 41 fathoms on the north flats of the Sandheads off the mouth of the Fraser River on March 14, 1953, by Mr. E. McDermid. Mr. T. F. Rothery, fishery inspector, sent the specimen to the Pacific Biological Station for identification, and it is now in the collection of fishes at this Station.

One earlier specimen of *A. sladeni* taken from British Columbia waters was recorded as *A. olfersi* (Clemens and Wilby, 1949, Bull. Fish. Res. Bd. Canada, No. 68, p. 106, fig. 54). Dr. W. A. Clemens kindly forwarded the specimen to the author for examination and it was found to agree in every respect with the description of *A. sladeni*.

A. sladeni is closely related to *A. olfersi* but is readily distinguished from the latter by the preopercular spines. In *A. sladeni* the lower preopercular spine is straight, directed downward and a little

TABLE I

PROPORTIONAL MEASUREMENTS OF THE 2 SPECIMENS OF *A. Sladeni* FROM BRITISH COLUMBIA

	Specimen A, caught, 1953	Specimen B, caught, 1935
Standard length: the distance from the tip of the snout to the end of the vertebral column (base of midcaudal fin rays)	48.0 mm.	33.0 mm.
Height in standard length	1.74	1.65
Length of dorsal blade	6.8 mm.	5.5 mm.
Height of dorsal blade (broken in spec. A) in length of its base	<2.95	2.2
Lower margin of orbit to lower preopercular edge (lower base of upper preopercular spine), which is the relative depth of the cheeks, in standard length	5.21	4.72
Distance between the top of the transparent area in the last abdominal photophore and the top of transparent area in the first *post*-abdominal (preanal) photophore in standard length	6.40	6.21

outward, but not forward; the upper preopercular spine is of moderate size and is directed slightly outward and backward, its tip extending past the rear margin of the preopercular bone. In *A. olfersi* the lower preopercular spine points downward, and is curved slightly forward and outward; the upper spine is very small or absent, and its tip does not extend past the rear margin of the preopercle in adults.

Argyropelecus lychnus, another form very close to *A. sladeni*, has sometimes been recognized as a separate species, e.g., Parr (1937, Bull. Bing. Ocean. Coll., 3(7): 46 and 50, fig. 19). The specimens at hand agree with *A. sladeni* rather than with *A. lychnus* in the last two features given in Table I.

The body proportions and the position of the photophores of the two specimens (Table I) are in agreement with those given for *A. sladeni* by Regan (1908, Trans. Linn. Soc. London, 2nd Ser., Zool., 12(3): 218), Parr (*op. cit.*), and Schultz (1938, Proc. U. S. Nat. Mus., 86: 147).

The distribution of *A. sladeni* is extensive, having been reported from the Pacific Ocean (off Panama, Hawaii, the Philippine Islands, and southern Japan), from the north and south Atlantic, Antarctic and Indian Oceans.—W. E. BARRACLOUGH, *Fisheries Research Board of Canada, Pacific Biological Station, Nanaimo, British Columbia.*

Reprinted from COPEIA, 1956, No. 2, p. 111, May 29
Printed in U.S.A.

SILVER HAKE, *MERLUCCIUS BILINEARIS*, IN THE GULF OF ST. LAWRENCE.—There are no records in the literature of silver hake, *Merluccius bilinearis* (Mitchill), occurring in the Gulf of St. Lawrence. However, the following reports of fishing operations show that it is found there:

West Coast of Newfoundland, deep channels, 1954–55, occasional specimens, reported by W. Templeman;

NW Cape Breton Is., 8–15 ft., Feb. 15, 1954, one, L. R. Day;

NW Cape Breton Is., 50 fms., June 20, 1954, three, 31–45 cm., F. D. McCracken;

Magdalen Is., Aug., 1954, several, F. D. McCracken;

S of Le Fond George, June 25, 1952, three, E. G. Sollows;

Four mi. NW Pictou Is., Sept. 21, 1952, a number of small specs., total wt. 35 lbs., E. G. Sollows;

Northumberland Strait, 17–21 fms., July 7–28, 1954, fifteen, 33–58 cm., F. D. McCracken;

Off Miramichi Bay, June 15–16, 1950, two, S. N. Tibbo;

Head of Miramichi Bay, 9 ft., Dec. 24, 1954, one, 17 cm., R. A. McKenzie;

NE Miscou Is., 16–20 fms., Aug.–Sept., 1955, two, 34–36 cm., R. W. Fassold;

Mouth of Baie-des-Chaleurs, 44–48 fms., July–Aug., 1953, small numbers, A. Marcotte and Y. Jean;

Mouth of Baie-des-Chaleurs, 28–60 fms., July–Aug., 1954, small numbers, A. Marcotte and Y. Jean;

The disposition of the specimens listed above is unknown except for R. A. McKenzie's, which is in the Royal Ontario Museum of Zoology, Toronto, Ontario.

These records and the reported increase of this species on the Grand Banks off Newfoundland (Dr. J. L. Hart, letter of June 14, 1955) may be due in part to the general warming of the waters on the whole Canadian Atlantic coast since 1940 (Lauzier, 1954, Fish. Res. Bd., Prog. Rept. Atlantic, no. 58. note no. 124: 6–11) and the general northern shift of the species (Taylor and Graham, 1953, Abstract, Ann. Proc. Intern. Comm. NW. Atl. Fish., 3: 68).

In 1914–15 neither eggs nor larvae of the silver hake were taken within the Gulf of St. Lawrence by the Canadian Fisheries Expedition (Dannevig, 1919, Dept. Naval Service, Canadian Fish. Exped., 1914–15, pp. 1–74) and, though plankton tows in August 1954 yielded considerable numbers of silver hake larvae off Nova Scotia, none were found within the Gulf of St. Lawrence (L. R. Day, letter of May 6, 1955).

Though the foregoing previously unpublished records indicate that the silver hake is quite widespread in the Gulf of St. Lawrence, it does not spawn there nor as yet has it been reported from the northwest portion of the "Gulf" or in the St. Lawrence River (Dr. V. D. Vladykov, letter of March 2, 1955). Consequently, the species should still possibly be considered only as a "stray" in the area under consideration.

The assistance of those who contributed to the preparation of this account is gratefully acknowledged.—R. A. McKenzie, *Fisheries Research Board of Canada, Biological Station, St. Andrews, N. B. and* W. B. Scott, *Royal Ontario Museum of Zoology, Toronto, Ontario.*

Reprinted from *Proceedings First International Conference on the Use of Antibiotics in Agriculture* publication 397 (1956) of the National Academy of Sciences—National Research Council

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CONTROL OF BACTERIAL SPOILAGE OF FISH WITH ANTIBIOTICS

It is well known that fish are almost invariably much more susceptible to bacterial spoilage when stored at ordinary refrigerator temperatures than are meats obtained from warm-blooded mammals. Probably one of the most important reasons for this is that fish are usually contaminated with those types of bacteria which thrive at low temperatures, namely the psycrophilic organisms. At temperatures around 0° C. these organisms normally have an extremely high growth coefficient (Q_{10}), and it has been shown that the flesh of fresh fish will spoil about twice as rapidly at 2.5 or 3° C. as it will at –1° C.(10). Moreover, fish presents an almost ideal substrate for growth of most spoilage organisms.

Though bacterial spoilage of fish may be prevented or delayed by such physical means as chilling, freezing, or heating, the possibility of adding relatively harmless chemical substances to inhibit microbial growth has long been the subject of extensive research. A survey of the early literature indicates that, over the years, a very wide and varied selection of chemical substances has been used with fish in attempts to delay spoilage. Our own early work, initiated in 1938(16), led to the use of sodium nitrite as an inhibitor of spoilage of fresh fish, and, indeed, this substance was very widely applied in the Canadian Maritime provinces during the last war. It is still used extensively, and is now legalized for use on fish in Canada. This substance, though undoubtedly useful, is by no means an ideal preservative, and we have therefore long sought for a more desirable substance.

The possible value of antibiotics in controlling bacterial spoilage of fish was investigated at this Station about 1943 when it was shown that penicillic acid was practically valueless for this purpose(17). Later, streptomycin and penicillin were studied and were also found relatively valueless as fresh fish preservatives(18). Early in 1950 about 15 antibiotics were investigated, and it was found that of these only three, namely chlortetracycline, oxytetracycline, and Chloromycetin were effective for both preservation of fish flesh and of beef(19). Since extensive work showed that, of the tetracycline group, chlortetracycline was always the most active, all our recent work has been conducted with this antibiotic. In our experience oxytetracycline is only about one-fifth as active as chlortetracycline for flesh food preservation, and tetracycline is less active than oxytetracycline. Since this early work was published we have also tested oxamycin and erythromycin, and found them relatively ineffective for flesh food preservation.

FRB. No. 438.

In some ways it is unfortunate that we have so far felt it necessary to devote most of the time spent on this problem to its more practical aspects. Consequently, considerable effort has been directed to practical problems concerning the use of chlortetracycline on fish, though some of the theoretical aspects of the problem have also been considered.

As with almost any applied research problems, certain difficulties have arisen but it has usually been possible to overcome these. We have conducted, usually at the request of the fishing industry, several quite large-scale experiments on the use of chlortetracycline under practical conditions. Some of the problems which have occurred, together with some of the results which have been obtained in the various experimental trials, will be discussed.

It was obvious when this work was initiated that chlortetracycline treatment should start as soon as possible after fish have been captured. The flesh of healthy fish is normally bacteriologically sterile(4), and as soon as the bacteria which occur in the slime or visceral tracts contaminate and penetrate the flesh, it becomes increasingly difficult to combat their activities. Several possible methods of application of chlortetracycline to fish at the time of capture were investigated, and it was concluded that, from the point of view of simplicity, incorporation in ice used for icing fish offers considerable promise. Though experiments did indicate that round or eviscerated fish could be dipped briefly in, say, 50 or 100 p.p.m. solutions of chlortetracycline immediately prior to icing them, this method is probably not too practical under some of the conditions which pertain on commercial vessels.

During the last two fishing seasons we have added approximately 1 μg./ml. (p.p.m.) of chlortetracycline hydrochloride to the water used in preparing flake-type ice at two different fish plants. This method is extremely simple and yields an ice which is not only indistinguishable from ordinary ice even when 4 μg. ml. of the antibiotic are incorporated, but also possesses outstanding bacteriostatic properties. The only real difficulty which we experienced in this work was the instability of chlortetracycline in so-called "hard" water, and this, in the particular instance, could be easily overcome by the addition of 200 p.p.m. of citric acid to the water in the tank containing the chlortetracycline stock solution to adjust the pH to about 3.5. Microbiological assays showed that in the unacidified water (pH 7.2) practically all antibiotic activity of added chlortetracycline disappeared in one day at 25° C.

The addition of chlortetracycline to commercial block ice presented certain difficulties, and one of these has not yet been completely overcome. The customary commercial procedure for preparation of block ice involves slow freezing in large rectangular cans immersed in circulating calcium chloride brine. There is always a tendency, especially if aeration is used, for dissolved crystalloids and colloidal or suspended particles to migrate to a small "core" near the centre of the ice blocks. Chlortetracycline, even in 1 μg. ml. concentration, offers no exception to this rule, and the problem of obtaining even distribution arose. It was found that, of a number of hydrophilic colloids studied, commercial carrageens (Irish moss extractives) and carboxymethylcellulose retarded migration of chlortetracycline effectively during freezing(8). Various methods of incorporating these colloids in the water used for making ice were studied, and difficulties such as relative insolubility in cold water or a tendency to form lumps had to be overcome. Experience showed that heating

carrageen suspensions in order to effect "solution" was impractical for large scale work, but it was found that prior mixing of the finely powdered material with about 3 parts of propylene glycol overcame this difficulty. However, with carboxymethyl cellulose an even simpler method was discovered, for it was found that if the finely divided material (less than 100 mesh) was mixed with about 3 parts of ordinary salt, it could be thrown into ice cans during rapid addition of cold water without any danger of lumping(2). The required amount of chlortetracycline hydrochloride may be added to the dry mixture.

Though the problem of difficulty of distribution of chlortetracycline appears to have been solved, another problem has arisen which could probably be overcome quite readily. In certain localities along the British Columbia and Alaska coastline the surface water in streams and lakes may be coloured brown by dissolved organic substances. Work at this Station (Dr. D. R. Idler, unpub.) has shown that ion exchange treatment removes the coloured substances so that the means for obtaining clear water are available. It would seem highly probable that the untreated water would make an effective chlortetracycline ice, and, in fact, use of such ice on a fishing boat showed that the white ventral surfaces of halibut are not stained by it. However, it is difficult to overcome the prevalent idea, which is probably quite without foundation, that ice made from such water is of inferior quality for icing fish.

Because of work initiated at our Station several years ago, renewed interest has been taken in the possibility of storing fish on boats or on shore in refrigerated sea water, or in salt solutions of similar concentration. It must be emphasized that this idea is by no means new, for an early French patent(6) indicates that some thought was given to application of this general method many years ago, and thorough investigations at the Halifax Station of this Board which were conducted about 1927 to 1930(10), (11) definitely established the superior keeping quality of fish so stored. This method offers one of the few ways by which fish may be maintained in non-frozen condition, and yet be only slowly susceptible to bacterial spoilage. The flesh is maintained at about 30° F. (−1.1° C.) while in ordinary melting ice the temperature can never be below 32° F. (0 °C.) and under usual commercial conditions is more likely to be between 35° and 37° F. The suggestion that fish might be held in refrigerated sea water on fishing boats was made by the writer in 1947 (9), and it was then pointed out that the method is quite possible because "fish wells" are commonly used on tuna boats to freeze the fish. Initial trials were made on small trolling boats(9), (13), (14), and these proved so successful that, during the present fishing season, a privately owned fish packing vessel has been equipped with three large aluminum tanks with capacity for around 45,000 pounds of fish. At least one large scow with a capacity of around 120,000 pounds of fish has been operating in the Alaska area this season.

Though storage and transport of fish in refrigerated sea water offers many advantages, experience has shown that certain difficulties may arise. Thus, under certain circumstances, there is a risk that bacterial spoilage may develop. This has definitely been shown to be a danger in instances where a very large load of slimy fish is placed in a tank in which the ratio of fish to sea water is very high. The sea water is heavily contaminated with protein and fish blood, and also with spoilage

bacteria from the slime and visceral cavities of the fish. This creates a heavy ba terial inoculum in a favourable growth environment, and even in a week at 0° C unpleasant odours may develop in the sea water and, although the fish may then selves appear firm and in good condition, they form a rather serious "bacteriological risk if, for any reason, they are stored further. This effect is shown in Table I whic illustrates results obtained in trials carried out on a large fish-packing vessel durin the past season. Though it would be possible to change the sea water regularly an thus preserve a clean medium, this is often neither practicable nor indeed desirabl This procedure would often create a condition where large extra refrigeration load would be required, and also there could be a very real danger that the fish migh absorb unduly large amounts of salt. We have found that the inclusion of onl 1 μg./ml. of chlortetracycline, or considerably less, will successfully hinder bacteria development for extensive periods, and that, even after one month in refrigerate sea water containing this antibiotic, fish may still be quite edible.

The question is often asked whether chlortetracycline, when added to ice or t refrigerated sea water, penetrates the flesh so that it can leave substantial residues In early work we attempted to ascertain whether penetration did occur, but thes

TABLE 1

EFFECT OF FOUR STORAGE TREATMENTS ON KEEPING QUALITY OF IMMATURE COHO ("BLUEBACK") SALMON

Type of storage	Bacteria (×10⁶) per gram after days*				
	2	9	16	23	30
Ordinary ice	0	14.0	342	535*	
	0	16.4	368		
	0	16.7	286		
	0	15.6	259		
		15.7	319		
Ice containing 1 μg./g. of chlortetracycline	0	1.80	6.77	124	
	0	.81	4.50	58	
	0	.85	3.97	61	
	0	.53	6.09	53	
		0.99	5.37	74	
Sea water	0	3.1	60.9	143	80†
	0	1.9	60.9	159	
	0	1.7	58.3	157	
	0	6.4	60.4	217	
		3.3	60.1	169	
Sea water plus chlortetracycline (1.4–0.7 μg./ml.)	0	0.26	2.60	47	23†
	0	0.26	4.77	47	
	0	0.21	1.59	40	
	0	0.34	2.60		
		0.27	2.89	46	

* Counts were made by a direct method after incubating steaks for 1 day at 10° C. except in those marked with a dagger where there was no incubation.

initial attempts were unsuccessful because the flesh of most of the local fish species examined were found to contain substances which gave a fictitious assay in the chlortetracycline pad plate assay procedure. This year we have reinvestigated this subject because we have found that the flesh of a local species known as the true cod (gray cod, *Gadus macrocephalus*) rarely exhibit this fictitious assay when the fish are in a fresh condition. To test the point, these true cod were iced with ordinary ice and with ice containing 1 μg./g. of chlortetracycline. At intervals fish were removed and different portions were assayed for the antibiotic, using the pad plate procedure. A simple extraction method was employed whereby the flesh was blended in the cold with 2.5 normal hydrochloric acid to pH 4.6. It was found that extracts obtained on centrifuging these blends at high speed could be placed directly on assay pads, dried in vacuum, and then applied to the inoculated medium as usual. Some results obtained in initial experiments are given in Table 2. They show that fictitious positive chlortetracycline assay values occur rather rarely with gray cod stored in ordinary ice, and that in fish iced with ice containing chlortetracycline there was a rather slight penetration after several days storage, and that this occurred most markedly in the visceral cavity samples with skin attached. Fish stored in refrigerated sea water containing chlortetracycline absorbed the antibiotic more markedly than did the iced fish (Table 3).

Studies of the rate of destruction or disappearance of chlortetracycline in heated fish flesh have occupied a certain amount of our time. Initial and early tests as shown in Table 4 indicated that destruction on heating was quite rapid. The positive

TABLE 2

PENETRATION OF CHLORTETRACYCLINE INTO GRAY COD STORED IN ICE CONTAINING 1 μg./g. OF THE ANTIBIOTIC

	Section of fish*	Days stored					
		0	1	2	4	7	10
Ordinary ice	V + S	0	0	0	0	0	0.2
		0	0	0		0	0
	V — S	0	0	0	0	0	0
		0	1.1	0		0	0
	T + S	0	0	0	0	0	0.2
		0	0	0			0
	T — S	0	0	0	0	0	0
		0	0	0		0	0
Chlortetracycline ice	V + S		0	0	0	0.4	0.9
			0	0		0.3	0.5
	V — S		0	0	0	0.5	0.7
			0	0		0.2	0.3
	T + S		0	0	0	0	0
			0			0	0.8
	T — S		0	0.6	0	0.2	0
			0	0		0	0

* V + S = Visceral cavity wall plus skin.
V — S = Visceral cavity wall without skin.
T + S = Tail end of fish plus skin.
T — S = Tail end of fish without skin.

TABLE 3

PENETRATION OF CHLORTETRACYCLINE INTO GRAY COD STORED IN SEA WATER CONTAINING 2.8 μg./ml. OF THE ANTIBIOTIC†

	Section of fish*	Chlortetracycline in μg./g. after days						
		0	1	2	4	5	6	7
Ordinary ice	V + S	0		0		0		0
	V − S	0		0		0		0
	T + S	0		0		0		0
	T − S	0		0		0		0
Chlortetracycline ice	V + S		1.5	3.0	1.5		2.16	3.0
	V − S		0	1.23	1.23		1.26	1.14
	T + S		1.2	1.23	1.5		1.26	2.55
	T − S		0	0	0		0	0

* V + S = Visceral cavity wall plus skin.
V − S = Visceral cavity wall minus skin.
T + S = Tail end of fish plus skin.
T − S = Tail end of fish minus skin.
† Steiner, G., and H. L. A. Tarr, unpublished.

values obtained after 20 and 30 minutes heating may have been due to substances which cause the fictitious chlortetracycline assay. Results obtained in more recent tests indicate that normal cooking of fish to internal temperatures of between 82 and 99° C. will destroy from about 80 to 90 per cent of added chlortetracycline (Table 5). The next step in this work will be to ascertain whether there are any detectable residues in flesh of fish iced with chlortetracycline ice after these have been subjected to normal cooking procedures.

We have carried out some exploratory experiments in attempts to ascertain what substance(s) in fish flesh occasion the fictitious chlortetracycline assay, and also in attempts to see whether quite small quantities of added chlortetracycline could be recovered. The technique used was as follows: Chlortetracycline (0.2 μg./g.) was added to lingcod flesh, which was blended at 0° C. at pH 4.6 and the bulk of precipitated protein removed by centrifuging. The liquid with the washings was further acidified and evaporated to dryness in vacuo at low temperature. The residue was thoroughly extracted with water-saturated n-butanol and this extract dried. The residue was washed with diethyl ether, dried and extracted with absolute ethanol. The two solvent extracts were evaporated to small volume and were chromatographed on paper treated with phosphate buffer pH 3.0. Bioautographs showed that small amounts of chlortetracycline were present in the ethanol extract. However, the ether extract also gave one zone of inhibition, and the ethanol extract two zones of inhibition which were rather diffuse and of lower Rf values than the chlortetra-

TABLE 4

DESTRUCTION OF CHLORTETRACYCLINE IN HEATED FISH FLESH CONTAINING 5 μg./g. OF THE ANTIBIOTIC

	CTC present after heating (μg./g.) minutes				
	0	10	15	20	30
Lingcod	5.1	2.4	1.5	0.6	0.45
Coho salmon	4.8	1.8	7.8	—	0.30

TABLE 5

INACTIVATION OF CHLORTETRACYCLINE ON HEATING FISH FLESH CONTAINING 6.5 AND 16.0 μg./g. OF THE ANTIBIOTIC*

Temperature (° C.)	Time required to attain temperature*	CTC content (μg./g.)	Time required to raise and maintain temperature 5′	CTC content (μg./g.) after holding 5′ at temp. given
6.5 μg./g. CTC, 60	5′ 40″	1.4	11′ 45″	1.4
	6′ 10″	1.2	11′ 0″	1.8
6.5 μg./g. CTC, 82	5′ 29″	1.4	11′ 35″	1.8
	8′ 0″	1.8	15′ 0″	1.2
6.5 μg./g. CTC, 99	5′ 8″	<0.3	10′ 0″	<0.3
	4′ 50″	0.8	10′ 30″	<0.3
16.0 μg./g. CTC, 60	8′ 45″	13.2	12′ 35″	2.8
	8′ 45″	11.2	12′ 35″	2.8
	8′ 45″	11.2	12′ 35″	2.8
16.0 μg./g. CTC, 82	9′ 27″	6.6	16′ 0″	2.0
	9′ 27″	5.4	16′ 0″	3.0
	9′ 27″	4.8	16′ 0″	2.4
16.0 μg./g. CTC, 99	14′ 0″	2.4	10′ 35″	0.98
	14′ 0″	2.4	10′ 35″	1.2
	14′ 0″	2.4	10′ 35″	0.92

* Steiner, G., and H. L. A. Tarr, unpublished.

cycline. These substances may be lipids, but as yet no attempt has been made to identify them. Attempts to recover chlortetracycline quantitatively when 20 μg. were added to 100 g. of fish were unsuccessful.

It is common knowledge that shellfish, and the cooked flesh materials obtained from them, are particularly susceptible to bacterial spoilage. There has never been a completely satisfactory explanation for this but it is probably largely because the pH of their muscle tissues is normally considerably above 7. Thus, in one of our experiments we found that cooked crabmeat had a pH of approximately 7.9. The meat of these shellfish requires considerably higher concentrations of chlortetracycline or oxytetracycline than does that of fish where the post-mortem muscle pH is usually between 6 and 7. Probably this is because chlortetracycline is quite unstable at pH values above 7.0. In one test we found about 10 times more chlortetracycline was required to preserve cooked crabmeat than was required to preserve various kinds of fish. This has also been the experience of those at the Marine Laboratory, University of Miami, who have been concerned with the preservation of fresh shrimp in either refrigerated sea water or in ice(5), (12). Thus they have reported that between 5 and 8 parts per million of chlortetracycline must be added to refrigerated sea water in order to bring about really successful preservation of shrimp. Similar concentrations of this antibiotic must be added to flake or block ice if successful preservation of shrimp against bacterial spoilage is to be obtained. Recent studies in California(7) have indicated that low concentrations of chlortetracycline and oxytetracycline which will preserve fish effectively are not successful with California shrimp.

There is, unfortunately, little published information on results of research conducted in other laboratories on fish preservation with antibiotics. In California a series of tests in which fish fillets were dipped in two parts per million solutions of various antibiotics prior to storing them at about 45° F. has been carried out(7). Using trimethylamine nitrogen, total volatile nitrogen, and the volatile reducing substances test as criteria of bacterial spoilage, it was found that the chlortetracycline dip gave the most outstanding preservative effect, and that oxytetracycline was less effective. More information on preservation of fish in different localities using antibiotics would certainly seem desirable.

In view of the success attained with relatively low concentrations of chlortetracycline, and because it is known that living fish will withstand quite high concentrations of this and certain other antibiotics in the water in which they swim, it seemed of interest to attempt to determine whether fish, if permitted to swim in chlortetracycline-containing sea water, would eventually have relatively sterile visceral tracts. Experiments of this kind are rather complicated, because it would appear from the literature that the visceral tracts of non-feeding fish are relatively sterile bacteriologically, while those of feeding fish are normally fairly heavily contaminated with bacteria. Due to very limited experimental facilities we have only been able to perform a few tests. The results (Table 6) indicate that the data we have obtained so far are rather inadequate, but they do show that when sea fish are permitted to swim for a day in sea water containing 5 p.p.m. of chlortetracycline, the antibiotic can be recovered from the mixed visceral organs, and that it is by no means certain that it causes a definite reduction in the bacterial population(3). More data with both fresh water and sea fish would be of interest. It would be desirable if possible to conduct such tests for some days or weeks, using feeding and non-feeding fish, and to perform both microbiological assays and bacterial counts on individual organs in the visceral cavity as well as on the digestive tract itself. The problem may be complicated by slow penetration of the antibiotic into organs such as the pyloric caeca and by the emergence of chlortetracycline-resistant bacterial strains.

The sensitivity of nearly all normal spoilage bacteria present in fish to chlortetracycline is very interesting. In our earlier work we found quite consistently that when fish containing 1 μg./g. of this antibiotic was stored at 0° or 4° C., nearly all bacteria were prevented from growing, but after about two weeks the flesh was richly invaded by yeasts and occasionally by moulds. We have been interested, consequently, in trying to obtain information on how this antibiotic exerts its

TABLE 6

VIABLE BACTERIA (per g.) AND CHLORTETRACYCLINE (μg./g.) IN THE VISCERA (stomach, pyloric caecae, liver, spleen, intestines, etc.) OF ROCK COD (*Sebastodes* sp.), HELD ONE DAY IN SEA WATER

	Experiment 1		Experiment 2		Experiment 3	
	Bacteria	CTC	Bacteria	CTC	Bacteria	CTC
Sea water alone	———	—	1,000,000*	—	50,000	0
Sea water + 1 μg./ml. CTC.....	1,000,000	0.22	———	—	———	—
Sea water + 5 μg./ml. CTC.....	———	—	18,000	—	48,000	1.2

* These fish died due to faulty aeration.

activity. There is far too little known regarding the mode of action of antibiotics so that any information which we might secure could be of value. There are probably many ways by which such a problem could be attacked, and we have initiated the somewhat obvious and possibly crude idea of attempting to determine what differences there may be in the metabolic pattern of a typical organism obtained from fish both before and after it has become very resistant to chlortetracycline. The work has as yet not proceeded very far, for it has taken a considerable time to obtain a very resistant organism. Thus it was found that the particular culture with which we have been working was initially susceptible to small fractions of 1 μg./ml. of chlortetracycline, and that, during the initial weeks of almost daily transfer in an ordinary medium, the sensitivity only gradually diminished. During the last few weeks of this transfer period, which will soon have extended to about four months, the resistance to the antibiotic has increased by leaps and bounds so that the organism will grow cheerfully in concentrations in excess of 1000 μg./ml.

The possibility of using chlortetracycline to retard post-mortem bacterial spoilage in whales is being explored. Whales are warm-blooded mammals which may often weigh over 50 tons, and their visceral tracts are richly contaminated with strict anaerobes of the genus Clostridium. There is also some evidence that the flesh or blood vessels of living whales may be contaminated with these organisms, though this does not appear to be entirely conclusive(15). Where whales are processed on factory ships there may be no unduly long interval between time of capture and processing, but when the nature of the fishery is such that processing is carried out at a shore plant, the whales may be towed for a few days and extensive anaerobic putrefaction may occur. Sperm whales appear to be peculiarly prone to post-mortem bacterial putrefaction since obvious spoilage may occur within 24 hours of death. In an attempt to overcome this we have been carrying out some experiments to ascertain whether the introduction of chlortetracycline into the visceral cavity of whales post-mortem will cause a transient preservation which will overcome serious bacterial spoilage until the animals are cut up. So far the method of introducing the chlortetracycline has been by sucking an aqueous solution into the air line used for inflating the mammals prior to towing them. In this work we have allowed about 35 g. of chlortetracycline per whale, which would be about 1 μg./g. calculated on the basis of a 50-ton whale, or 5 to 10 μg./g. based on visceral organ weights of between 5 and 10 tons. This work has been ably conducted by Mr. P. B. Crean, who had considerable prior experience when attached to the British factory ship "Balaena." The results of all tests made so far have been very encouraging (Table 7), and it is hoped that more extensive work may be carried out next year. In one whale a 25 g. charge of chlortetracycline hydrochloride was placed in a linen bag in the bomb head of the harpoon. The cloth material was recovered and after drying was found to contain about 2.5 g. of the antibiotic. This indicates that it might be possible to introduce the antibiotic in this manner without any serious decomposition.

Before permission may be granted to add any substance to a food intended for human consumption, such a substance must advisedly pass rigorous tests to ensure that no harm will come to the eventual consumer. The concentrations of chlortetracycline used throughout our experiments have been extremely small and amount to a single rather small normal daily oral dose (1 gram) in, for example, one ton of

Table 7

CONTROL OF POST-MORTEM BACTERIAL SPOILAGE OF WHALES WITH CHLORTETRACYCLINE* (55 g. per whale)

Whale	Location of sample	Bacteria $\times 10^6$/g. by direct count	
Untreated 44′ male sperm, 43 hr. post-mortem	Deep muscle from behind skull	48	*
	Outer muscle from back	90	2.1% F.F.A. in oil
	Deep muscle near backbone	170	
	Liver tip	1850	
	Deep liver	1700	
Treated 50′ male sperm, 43 hr. post-mortem	Deep muscle near backbone	3	0.7% F.F.A.
	Deep muscle behind skull	7	
	Deep muscle near tail	2	
	Muscle near belly	1	
	Liver tip	37	
Treated 44′ male sperm, 48 hr. post-mortem	Surface muscle close to blubber	637	0.7% F.F.A. in oil
	Deep muscle near backbone	50	
	Deep muscle opposite injected side	2	
	Liver tip	5	
	Muscle near liver	34	
	Deep liver	100	
	Muscle near CTC injection	0	
Untreated 41′ female humpback, 26 hr. post-mortem	Deep muscle near backbone	40	
	Deep muscle behind skull	353	
	Surface muscle close to blubber	450	
	Deep liver	143	
	Liver tip	0.5	
	Belly muscle	1	
Treated 33′ male humpback, 26 hr. post-mortem	Deep muscle near throat	5	
	Deep muscle near backbone	0	
	Deep muscle near tail	0	
	Deep liver	0.8	

* >2.0% Free Fatty Acids indicates oil unfit for Grade 1. Crean, P. B., and H. L. A. Tarr, unpublished. *See* also Fish. Res. Bd. Canada, Prog. Rep. Pacific **104**, 1955 (in press).

ice. As shown in our experiments, which have been reviewed above, only a fraction of this is ever likely to enter fish, and it is extremely doubtful if the average fish treated with chlortetracycline ice would have more than .2 or even .1 p.p.m. of the antibiotic in the flesh. In fact, the amount is so small that it is only rarely that any can be detected by the pad plate assay procedure, and that after fairly prolonged storage in ice. Since fish are almost invariably cooked prior to use, it is extremely doubtful whether it would ever be possible to detect any chlortetracycline in their flesh as consumed even if they had been stored for considerable periods in chlortetracycline ice.

One danger which does occasionally exist with certain food additives is that of suppression of the natural spoilage or desirable microbiological flora and promotion of growth of certain undesirable or potential toxin-forming food spoilage organisms. Thus, sorbic acid is known to favour the growth of certain Clostridia such as *C. botulinum*. To test this point we have inoculated fish flesh with spores of Type

E. *Clostridium botulinum*, some of the fish samples containing 1 μg./g. of chlortetracycline and others being free of the antibiotic. Serial dilution tests of these samples for *C. botulinum* after storing for three days at 10 C. showed that no appreciable growth of the anaerobe occurred in the samples containing the added antibiotic, while in those without the added antibiotic there was a slight increase in growth of *C. botulinum*. A rather similar experiment was carried out using a known food poisoning strain of *Staphylcoccus aurens* ($\propto$). Bacterial counts indicated that the growth of this organism was definitely suppressed in the presence of the chlortetracycline(1). It can certainly be concluded that treatment of fish with chlortetracycline is more likely to suppress growth of these food spoilage organisms than to enhance it.

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The B-vitamins of Cod and Haddock

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The statement that fish is a food of high nutritive value, is usually based on the good quality of fish proteins. However, many more constituents determine the nutritive value of a food, as for example the fats, minerals and vitamins. There is no doubt that fish proteins are of high biological quality but the question arises: how does fish compare with other proteinaceous foods, with respect to the other constituents.

Amongst the latter, vitamins are in an important position, and meats besides being rich sources of protein, contain relatively large amounts of B-vitamins, as may be seen in Table I. However, the B-vitamin content of fish has not been studied thoroughly. For that reason, this laboratory began an investigation, some years ago, to find at least a partial answer to the above question: several B-vitamins were determined in cod and haddock, and the effect of freezing, smoking and storage on the vitamin content was studied. This paper will summarize the results and briefly discuss them.

Materials

Round fish: the flesh of Atlantic cod (*Gadus callarias*) and haddock (*Melanogrammus æglefinus*) obtained within 12 hours after the fish was caught.

Fresh fillets: commercial fillets, ob-

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as for meats, are the results of relatively few determinations and hence, they do not necessarily show the average values that would be found if analyses of much larger numbers of samples were carried out. They serve only as indicators of the order of magnitude of the B-vitamin content of the samples.

Table IV. Average B-vitamin content of cod and haddock*.

Vitamin	Cod	Haddock
	μg/g	μg/g
Thiamine	3.1	2.6
Riboflavin	2.1	1.2
Niacin	119	189
Pantothenic acid	8.5	5.7
Vitamin B_{12}	0.047	0.059

*Results expressed on the moisture-free basis.

Summary

Microbiological assays of thiamine, riboflavin, niacin, pantothenic acid and vitamin B_{12} were carried out on a number of samples of fresh and processed cod and haddock. The results indicated:

1. a wide variation between samples of one class,

2. no loss of vitamins upon freezing, smoking and cold storage,

3. B-vitamin levels in these fishes, very similar to those of meat.

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PENETRATION OF CHLORTETRACYCLINE INTO FISH MUSCLE AND ITS DESTRUCTION BY HEAT[1]

By G. Steiner and H. L. A. Tarr

ABSTRACT

The concentrations of chlortetracycline (CTC) in flesh of fish iced with ice containing 1 μgm./gm. of the antibiotic, or held in refrigerated sea water containing 2.8 μgm./gm., were determined by microbiological assay. With iced fish relatively small amounts penetrated the fish, and these occurred largely in the visceral cavity walls and especially in samples in which the skin was not removed. Fish stored in sea water containing CTC absorbed the antibiotic more markedly than did those stored in ice, and with these also the skin and visceral cavity walls had the highest concentrations. Destruction of CTC in fish flesh was determined in samples heated to 60°, 82°, and 99°C.

Experiments indicate that chlortetracycline (CTC) is probably by far the most effective antibacterial agent yet discovered for fish preservation (4, 5, 6, 7, 8, 9). However, the amounts of CTC which are absorbed by whole or eviscerated fish stored in ice or in refrigerated sea water containing only a few micrograms per gram of the antibiotic have not been determined successfully. Also, destruction of CTC in heated fish muscle has been studied only to a very limited extent (7). Work on these problems has been delayed because it has been found that extracts of normal muscles of many species of fish give inhibition zones in the usual pad plate microbiological assay for this antibiotic. The finding that flesh extracts of gray cod (*Gadus macrocephalus*) only give such fictitious assays occasionally has facilitated experimental work on the above problems.

EXPERIMENTAL

Gray cod which had been iced on fishing boats for one or two days were eviscerated and washed lightly with running tap water. They were then iced thoroughly in galvanized containers placed in an insulated box (7), one group with ordinary crushed block ice and another with similar ice containing 1 μgm./gm. of CTC distributed by the carboxymethylcellulose – sodium chloride method (1). In another experiment similar fish were stored in refrige-

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rated circulating sea water at $-1°\pm0.5°$C. with and without 2.8 μgm./ml. of CTC.

At intervals fish were removed from their respective treatments. They were filleted without washing and only one of the fillets was skinned. Two samples were taken from each fillet, one from near the tail and the other from the visceral cavity wall and including the membrane lining of the visceral cavity. The samples were blended promptly with twice their weight of distilled water and sufficient 2.5 *N* HCl to adjust the suspension to pH 4.5. They were centrifuged at about 20,000*g* and at 0°C., the supernatant liquids being promptly frozen until microbiological assays could be made. The pad plate microbiological assay for CTC described by Broquist and Kohler (2) was used. This method is not usually sensitive to much less than 0.01 μgm. of CTC per 0.5 in. filter paper assay disk. Since 0.1 ml. of a 1:3 dilution of fish muscle was applied to each pad the limit of sensitivity of the assay was generally assumed to be 0.3 μgm. of CTC per gram of muscle and was never more than 0.2 μgm. per gram.

The results of two similar experiments made to ascertain the amount of CTC penetration occurring with iced fish are given in Table I. It will be seen

TABLE I

PENETRATION OF CTC INTO EVISCERATED GRAY COD STORED IN ICE CONTAINING 1 μGM./GM. OF THE ANTIBIOTIC

Section of fish*	CTC in μgm./gm. after days†							
	0	1	2	3	4	5	7	10
Ordinary ice								
V+S	0	0	0	0	0		0	0.2
	0	0	0	0		0	0	0
V−S	0	0	0	0	0		0	0
	0	1.1	0	0		0	0	0
T+S	0	0	0	0	0		0	0.2
	0	0	0	0		0	0	
T−S	0	0	0	0	0		0	
	0	0	0	0.5		0	0	
CTC ice								
V+S		0	0	0	0		0.39	0.9
		0	0	1.1		0	0.30	0.5
V−S		0	0	0.45	0	1.3	0.54	0.7
		0	0	0			0.30	0.3
T+S		0	0	0	0		0	0
		0	0	0		0	0	0.8
T−S		0	0.6	0	0		0	0
		0	0	0		0	0	0

* *V+S = Visceral cavity wall with skin.*
V−S = Visceral cavity wall without skin.
T+S = Tail end of fish with skin.
T−S = Tail end of fish without skin.
† 0 = *<0.3 μgm./gm.*

that fictitious CTC assay results such as occur with many species of fish are found only very occasionally with gray cod. In general it appears that, in fish iced with ice containing CTC, the antibiotic occurs largely in samples containing skin and especially in those taken from the thin visceral cavity walls, and is found regularly only after the fish have been over five days in the ice. During the first five days in CTC ice there is only occasional erratic penetration, and since a few of the samples taken from fish from ordinary ice gave fictitious assays, it is possible that certain of the positive results obtained with fish from CTC ice may have been due in part or entirely to a similar cause.

The results obtained with fish held in refrigerated sea water containing CTC (Table II) showed that definite penetration occurred earlier than with fish held in CTC ice, but that with these also the visceral cavity wall and skin

TABLE II

PENETRATION OF CTC INTO EVISCERATED GRAY COD STORED IN ORDINARY SEA WATER AND IN SEA WATER CONTAINING 2.8 μGM./GM. OF THE ANTIBIOTIC

Section of fish*	CTC in μgm./gm. after days*						
	0	1	2	4	5	6	7
Ordinary sea water							
V+S	0		0		0		0
V−S	0		0		0		0
T+S	0		0		0		0
T−S	0		0		0		0
Sea water with CTC							
V+S		1.5	3.0	1.5		2.16	3.0
V−S		0	1.23	1.23		1.26	1.14
T+S		1.2	1.5	1.5		1.26	2.55
T−S		0	0	0		0	0

**As in Table I.*

containing samples had the higher concentrations. It is of interest that the muscle from the tail region without skin gave no positive assay for CTC even after seven days' storage.

The effect of different heating times and temperatures on destruction of CTC in fish muscle was determined as follows: Muscle from a strictly fresh gray cod was blended with an equal quantity of distilled water, or CTC solutions containing 10 and 20 μgm./ml. of the antibiotic, the pH of the blends being 6.5. Twelve gram amounts of the suspension were centrifuged at 3°C. in 15.8×762 mm. stainless steel tubes at 26,000*g* in a Spinco preparative ultracentrifuge, the supernatant liquids being discarded.

The samples were stored at −20°C. for a few days until required. The temperature of the samples was then adjusted to between 0° and 1°C. and a thermocouple inserted in the center of the contents of each tube. Microbiological assays showed that the untreated flesh samples both before and after heating (*vide infra*) contained no measurable CTC. Samples con-

taining CTC were placed in water baths maintained at temperatures a few degrees above those to which the fish were to be heated, namely 60°, 82°, and 99°C. One series was heated until the desired temperature was attained, and another for five minutes after this temperature was reached. The tests were conducted in duplicate or in triplicate (Table III). After heating, the samples were frozen promptly in a bath of solid carbon dioxide and methanol.

TABLE III

INACTIVATION OF CHLORTETRACYCLINE ON HEATING FISH FLESH CONTAINING 6.5 AND 16.0 μGM./GM OF THE ANTIBIOTIC

Temperature (°C.)	Time required to attain temperature	CTC content (μgm./gm.)	Time required to raise and maintain temperature 5 min.	CTC content (μgm./gm.) after holding 5 min. at temp. given
6.5 μgm./gm. CTC*				
60	5 min. 40 sec.	1.4	11 min. 45 sec.	1.4
	6 " 10 "	1.2	11 " 0 "	1.8
82	5 " 29 "	1.4	11 " 35 "	1.8
	8 " 0 "	1.8	15 " 0 "	1.2
99	5 " 8 "	<0.3	10 " 0 "	<0.3
	4 " 50 "	0.8	10 " 30 "	<0.3
16.0* μgm./gm. CTC				
60	8 " 45 "	13.2	12 " 35 "	2.8
	8 " 45 "	11.2	12 " 35 "	2.8
	8 " 45 "	11.2	12 " 35 "	2.8
82	9 " 27 "	6.6	16 " 0 "	2.0
	9 " 27 "	5.4	16 " 0 "	3.0
	9 " 27 "	4.8	16 " 0 "	2.4
99	14 " 0 "	2.4	10 " 35 "	0.98
	14 " 0 "	2.4	10 " 35 "	1.2
	14 " 0 "	2.4	10 " 35 "	0.92

**Determined by microbiological assay of unheated samples.*

They were kept frozen for several days until microbiological assays could be made to determine the CTC content. The extraction method used was similar to that recorded above except that an equal volume of water was used.

The results (Table III) indicate that at 60° and 80°C. there is about the same degree of destruction of CTC, and that this is not appreciably increased by heating for five minutes after the temperature is attained. In samples heated to 99° there was a much more marked destruction of CTC and further destruction occurred when the samples were kept an additional five minutes at this temperature.

DISCUSSION

The results have shown that gray cod rarely contains indigenous substances which cause fictitious CTC assay results. These fish, when stored in ice containing 1 μgm./gm. of the antibiotic, absorb small amounts after about five days, but this occurs mainly in the thin visceral cavity walls and in the skin. As yet the average CTC content of whole eviscerated fish so iced has not been determined, but it is doubtful if it would exceed 0.01–0.2 μgm./gm. after normal storage periods not exceeding 10 days.

It has long been recognized that CTC is unstable, especially when stored in dilute solutions at pH values above 4.5, and also when subjected to heating. The protective effect exerted by various colloids and other naturally-occurring substances against heat destruction of CTC has also been recorded (3). Isoaureomycin, which was first isolated from CTC following alkali treatment (10), is also formed when flesh foods containing the antibiotic are heated.* It is apparently inert, or almost inert, bacteriostatically (3).

The present work has shown that heating, such as could occur in the usual rather mild cooking procedures advocated for fish, destroys a very large percentage of the CTC as judged by microbiological assays.

The nature of the residual antibacterial activity occurring in heated fish flesh has not as yet been determined, but it could be due to CTC itself which has been protected by fish muscle constituents, or to a degradation product which has antibacterial activity. The latter assumption would appear unlikely since isoaureomycin, which is probably formed on heating CTC-containing fish flesh, reportedly has little antibacterial activity (3). It remains to be determined whether detectable CTC residues occur in fish which have been iced with CTC-containing ice and have subsequently been cooked by normal procedures.

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RECENT BIOLOGICAL RESEARCH IN GREENLAND

T. W. Böcher, K. Holmen, and M. J. Dunbar

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RECENT BIOLOGICAL RESEARCH IN GREENLAND

T. W. Böcher*, K. Holmen*, and M. J. Dunbar†

Botany. By T. W. Böcher and K. Holmen[1]

Taxonomy

Vascular plants: The large amount of vascular plant material collected in southwest Greenland by the botanical expedition of 1946 has been published by Böcher (1952a), who has discussed several species in earlier studies (1950, 1951) and has written a monograph on *Carex Heleonastes-amblyorhyncha* in its entire circumpolar range (1952b). Material from other expeditions has been included in Sørensen's (1953) study of the difficult genus *Puccinellia*, and in his present research on the genera *Hierochloe*, *Calamagrostis*, and *Braya*, and in K. Holmen's systematic studies of the genus *Festuca*.

Our knowledge of the chromosome numbers in Greenland vascular plants has recently been advanced by a list of chromosome numbers of the Peary Land plants published by Holmen (1952), one conclusion being that the extent of polyploidy in that flora is not significantly higher than in other arctic areas, contrary to the theory that polyploidy should increase with worsening climatic conditions. A comprehensive review of the chromosome numbers in the Greenland flora, the work of a team consisting of C. A. Jørgensen, Th. Sørensen, and M. Westergaard, is approaching completion. T. W. Böcher is continuing his study of the *Arabis Holboellii* complex (1951), and has now included several North American races for comparison. In addition to cytological investigation, breeding experiments have established significant genetical differences between the Greenlandic and North American populations of the species. Cytological factors in the *Stellaria longipes* complex are also under study. Intensive research on the *Papaver radicatum* complex and other closely related species of *Papaver* is being carried out by C. A. Jørgensen.

There has long been a need for a concise handbook of the vascular plant flora of Greenland, and one is now being prepared by T. W. Böcher, K. Holmen, and K. Jakobsen. This handbook, which is designed for both teachers in the Greenland schools and for plant collectors, will list all the Greenland vascular plants and give their distribution within the country. The text will be in Danish, but there will be a foreword in English with

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[1]Text completed in 1953.

translations of the more important technical terms and a map of the floristic regions. An elementary botany in Greenlandic for school use, which will contain examples taken from the commonest Greenland species, is also planned by the same authors.

Bryophytes: Of all the plant groups, the bryophytes are the richest in species in Greenland. The principal source material, however, is still the collections made by S. Berggren and N. Hartz during the nineteenth century, and our knowledge of the group is fairly poor. The situation should soon be remedied, for since the Second World War comprehensive collections of bryophytes have been obtained from several areas. Thus K. Holmen made a study of the bryophytes round Søndre Strømfjord and Arsuk Fjord in west Greenland in 1946, and of Peary Land in the north and of Ella Ø and Clavering Ø in east Greenland in 1947–50. The Sphagnum species of this material are included in a work on all the Greenland Sphagna by Bodil Lange (1952), the Hepaticae by Eva Clausen and the Musci by K. Holmen will soon be ready for publication. Studies are also being made of the extensive material collected by K. Jakobsen from 1947–50 in the region between the Nugssuaq Halvø and Thule in west Greenland, and of smaller collections from other areas.

Lichens: The macrolichen flora of Greenland is fairly well known through the work of the Norwegian botanists B. Lynge, P. Scholander, and Eilif Dahl, but there is still much to be done. The large collections brought back by the Danish botanists M. Skytte Christiansen (mostly from Søndre Strømfjord and Arsuk Fjord in 1946), K. Holmen (from Peary Land in 1947–9), and K. Jakobsen (from the Nugssuaq Halvø in 1947, 1948, and 1950), is at present being studied by Christiansen, who has discovered several species of macrolichens not formerly recorded from Greenland in this material.

The microlichen flora is much less known. In the Scandinavian herbaria there are large collections of crustaceous lichens, but the determination of them requires an immense amount of microscope study, and the working up is a long process. Only a few genera, such as *Rhizocarpon*, are well enough known to permit phytogeographical discussion. At present the number of species with restricted distribution seems too large in proportion to the number of known circumpolar species. There is still a great amount of collecting to be done, but by trained lichenologists only, since a large number of crustaceous lichens are so inconspicuous that they may easily escape the notice of even experienced botanists.

Fungi: In the past, collections of Greenland fungi have been brought home by many expeditions. Most of the known species, however, were collected unintentionally on specimens of higher plants. E. Rostrup and J. V. Lind, who made a special study of herbarium specimens, have published a number of papers on Micromycetes found in this way, and our knowledge of the Greenland Micromycetes is probably fairly complete. Rostrup has also published scattered records of fleshy fungi, especially in his survey of 1888, in which most of the older records are summarized.

Comprehensive collections of Macromycetes and a study of their ecology were made in the Ivigtut, Godthaab, and Søndre Strømfjord areas in 1946 by M. Lange. Lange (1948) has also published a list of the Greenland Macromycetes which includes typical arctic species as well as elements of a steppe flora. In investigating the relationship of the Macromycetes flora, he found that the Greenland species tested were infertile with similar species from Europe and North America.

Algae: Recent publications include K. Holmen's collections of marine algae from Peary Land which have been worked up by Lund (1951), and the freshwater algae (Grönblad, 1952) and diatoms (Foged, 1953) collected by T. W. Böcher in southwest Greenland in 1946. Altogether 271 species were found in 42 samples from southwest Greenland, including several diatom species new to science. N. Foged is at present studying a series of diatom samples collected by Holmen in Peary Land, and his own large collections from the 1952 expedition to northwest Greenland sent out by the Commission for Scientific Investigations in Greenland. Also approaching publication are S. Lund's important collections of marine algae from Scoresby Sund and Ella Ø.

Plant geography

In southwest Greenland Böcher (1952a) found a significant floristic contrast between the coastal area and the inland region at the head of Søndre Strømfjord. In a local flora of 200 species of vascular plants there are 47 species which are absent or are very scarce in the coastal parts and 73 coastal species which become scarcer or are absent in the inland region. There is also a considerable difference between the vascular plant flora of the inland areas of Søndre Strømfjord and that of the more southerly Godthaab Fjord. It has been shown that a number of species which favour an Atlantic (maritime) climate have a limit of northern distribution running diagonally from the interior of Godthaab Fjord to the coast at Holsteinsborg, a line which coincides with the isohyets and with the lines of equal mean annual temperature range. On the basis of the observed floristic differences and the distribution maps for a large series of plants, it has been possible to divide southwest Greenland into floristic districts. Johannes Gröntved has also been working on the flora of southwest Greenland for many years, and during the 1953 season was collecting there with C. A. Jørgensen.

The comprehensive plant collections brought back by the Geological Survey of Greenland expedition to northwest Greenland will shortly be published by K. Jakobsen, who was responsible for most of the botanical collecting, and is preparing a local flora of the region between the Nugssuaq Halvø and the Thule district.

A local flora of the vascular plants of Peary Land is about to be published by K. Holmen, who has also found significant differences between the coastal and inland floras. Of some 90 species collected in that northernmost region by the Pearyland expedition of 1947–50, only 27 were previously known from the area.

In a recent report (Holmen and Mathiesen, 1953) describing the finding of *Luzula Wahlenbergii* in northeast Greenland, a species not known from Greenland hitherto, an analysis of the vegetation in which the species is found is included.

The distribution of mosses and lichens also has interesting features. K. Holmen's investigations in Søndre Strømfjord and Arsuk Fjord have shown that the composition of the moss flora varies greatly both from the coast inland and also from north to south. The lichen flora of southwest Greenland has recently been studied by Dahl (1950) who finds that the macrolichen flora there is almost identical with that of Scandinavia, a fact that can be explained by the survival of the flora on ice-free refugia during the last ice age. The North American element in the macrolichen flora of southwest Greenland is very small. A closer study of the lichens of the Rocky Mountains, and of the Ural' and Altai ranges, is still badly needed for an understanding of the relationships within the arctic lichen flora. K. Holmen's collections from Peary Land, according to Skytte Christiansen, indicate the presence of a high-arctic, arid element in the flora which Greenland has in common with Ellesmere Island. Christiansen's own collections from the continental areas in Søndre Strømfjord point to the appearance of a steppe or desert element in the lichen flora on loess soils on southern slopes.

Ecology

The work of the French botanist H. de Lesse in the Eqe region at the head of Disko Bugt (de Lesse, 1952) is an important contribution to our understanding of the vegetation of central west Greenland. He has discussed the eleven main types of plant community in detail and has given tabular analyses, soil profiles, pH determinations, and measurements of organic content of selected patches.

In Böcher's (1954) study of the plant communities in southwest Greenland, the vegetation is divided phytogeographically on the basis of the distribution of the species, especially their climatic and soil preferences. Two main vegetational areas: oceanic and continental are described. Each area is subdivided into vegetation complexes which have a homogeneous ecology, and again into vegetation types which are of homogeneous appearance.

Further vegetational descriptions and ecological data are in preparation by K. Holmen from Peary Land, by H. Mathiesen from northeast Greenland, and by K. Jakobsen from northwest Greenland. Investigations of plant communities dominated by lichen or by moss are being made by Skytte Christiansen and K. Holmen respectively.

In 1948 S. Nielsen began a quantitative study of the phytoplankton of Disko Bugt. His results will be published with other recent analyses using radioactive carbon (C-14) to study the organic production. N. Foged's paper on the west Greenland diatoms (1953) contains abundant ecological data including halobion and pH spectra for the waters investigated.

Tree planting

In 1948 C. A. Jørgensen and the late C. H. Bornebusch studied the present tree growth and the possibilities for future planting in southwestern Greenland. Since then, in collaboration with Syrach Larsen, Jørgensen has grown a large stock of young trees in Denmark of various forest species which should be suitable for Greenlandic conditions. Under Jørgensen's supervision these trees have been planted out in the most sheltered valleys of south Greenland, and a tree nursery has bee nestablished at Uperniviarssuq near Julianehaab.

Future work

The most immediate need is for investigations of the botanically least known regions of Greenland by qualified botanists. Districts which should be visited as soon as possible include the areas between Peary Land and the Thule district, between Danmarks Fjord and Skærfjorden, and parts of southeast Greenland. Reinvestigation of the inner Scoresby Sund area is also needed as the ecological conditions seem to be especially interesting, and there are possibilities of finding isolated occurrences of continental Siberian or North American species. Finally, the great amount of botanical work which has been done in Greenland should be crowned with the publication of a complete and scientific Greenland flora, including vascular plants, mosses, and thallophytes. Such a work would be an important milestone in Greenland research, and would be invaluable for future investigations of the country.

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II. Zoology and Marine Biology. By M. J. Dunbar[1]

Terrestrial and freshwater faunistic studies

The "Zoogeographical investigation of Greenland", organized under the Greenland Department of the Danish Ministry of State, and with the cooperation of the Zoological Museum of Copenhagen University, began field work in 1948, and has as its final objective the complete exploration and classification of the land and freshwater fauna of Greenland from the zoogeographical point of view. The investigation is carried out by Christian Vibe with the assistance, in the field, of young Greenlanders who show special interest in natural history.

During the six years 1947 to 1952, Vibe covered most of west Greenland in this way, from Thule to the Julianehaab district. In the 1953 season he worked from Mesters Vig on the east coast along the shores of Kong Oscars Fjord. All land animals and all freshwater animals are collected, and the insects, which are being worked up for publication, have so far yielded over 100 species new for Greenland and over 30 new to science.

This study of the Greenland fauna, and especially of the insects and mammals, has given support to the view that there must have been an ice-free area in the north of Greenland during the Pleistocene glaciation, which served as a refuge for much of today's "high-arctic" fauna in north Greenland as a whole. It also supports the theory, first put forward by Murray (1912) and by O. Pettersson (1913), that the glaciation caused the Polar Basin and surrounding land areas to be isolated more or less completely from what we know today as subarctic and boreal regions, even to the extent of containing, to a large degree, the polar water, and preventing the Atlantic Drift from affecting the climate of the polar regions. Thus the southern part of Greenland, on this view, might have been milder than it is at present, owing to the blocking of the Atlantic water south of the barrier. The barrier is taken to have been along the Wyville Thompson ridge and its extension westward to Greenland.

The present-day fauna is divided into a northern "high-arctic" and a southern "low-arctic" element, the former restricted to the extreme northwest, the north, and the northeast, and the one sharply separated from the other by the conditions of winter climate. In the high-arctic climate the mean summer temperature is below 6°C, and the winter temperature is always

[1]Text completed in 1953.

below freezing, never showing the sharp oscillations of freeze and thaw which are so common in the low-arctic winter. The high-arctic fauna, including (among the mammals) muskox, caribou, Greenland lemming, weasel, arctic hare, and fox, is circumpolar in distribution. In low-arctic areas the caribou and hare tend to be restricted to high altitudes, and the fox to the tidal zone, in feeding habits, and they differ racially from their counterparts farther north.

The low-arctic insect fauna of Greenland contains a large number of boreal species, partly nearctic, partly palearctic, partly holarctic, and partly confined to Greenland. They are taken to be the remainder of an originally much richer boreal fauna which in Europe and North America was in part extinguished during the glaciation or has since succumbed in competition with immigrants. Scattered occurrences of this fauna are to be found on both coasts of Greenland up to the 72nd parallel.

Vibe has also undertaken a biometric study of the Greenland fox material collected in recent years and to be found in the collection of the Zoological Museum in Copenhagen, which has resulted in the conclusion that not less than three distinguishable races exist in Greenland: one in the extreme northeast, in common with the Canadian Arctic Archipelago, one with a discontinuous distribution in northwest and east Greenland, and one in the southwest.

Marine and terrestrial zoology in Peary Land and the northeast

The zoologist on the Danish Pearyland expedition, Palle Johnsen, made collections of both land and marine animals, to be worked up and published in due course; and our knowledge of the biology of the plankton and other marine fauna in pure polar water should be further advanced by the sending of a young biologist to Danmarks Fjord in 1953, on the northeastern corner of Greenland, to make a year's study of the biological cycle in the sea. The results of this study should be extremely interesting, for it will shed light on the still obscure problem of the production level of life in the polar sea itself, and allow direct year-round observation of the growth rates of planktonic forms in that very cold water.

Fisheries and marine biological investigations in west Greenland

These are the largest-scale biological researches in Greenland, and have been so for a long time, for the good reason that the marine resources of Greenland are by far the most important to the country's economy. They began, in the present organization, in 1908, under A. S. Jensen, and have now for many years been led by Poul M. Hansen. The investigations expanded greatly when it became clear that the increased Atlantic influence in the west Greenland waters, first observed about 1917–20, was to endure for some time, and that therefore the cod and halibut fisheries, especially the former, would reach first-rank importance if properly developed. A new research vessel, the 38-ton *Adolf Jensen,* was brought into use after the last war, and several motor boats are also engaged in the field work.

Much of this work is continued routine, involving the recording of the size and age of the fish taken each year, and of their migration. Current developments, and future plans, may be summarized under the following headings:

Cod: Particular attention is being paid at present to the stocks of Atlantic cod (*Gadus callarias*) in Godthaab and Ameralik fjords. These fjords lie side by side but are of quite different kind: Godthaab Fjord is a so-called "Atlantic" fjord, with a deep or much indented threshold allowing the passage of Atlantic water at all depths, and Ameralik Fjord is an "arctic" fjord with a high submarine threshold which keeps out the deeper water and therefore builds up in the deeper parts of the fjord a local water-mass of low temperature, below zero Centigrade. The cod in the two fjords are of similar year-class composition and otolith type, different in both characteristics from the rest of the west Greenland stock, but the Ameralik population does not stay in the fjord all the year round. It moves out with the caplin (*Mallotus villosus*)—an important food organism of the cod—in the summer. The Godthaab Fjord stock remains in the fjord the whole year and has a slower growth rate than the Ameralik cod. The Godthaab cod are extremely numerous, and their smaller size is no doubt mainly due to overcrowding. It is thought that the Ameralik cod are the surplus of the Godthaab stock.

Three recent observations on the west Greenland cod, published in Hansen's report on fishery research for 1952, are interesting and so far largely unexplained: (1) The largest cod and the older year-classes are found in the northern part of the west Greenland waters (Disko Bugt and northward). (2) The average length of the cod taken in the commercial catch in 1952, year-class for year-class, was significantly lower than during the years 1931–9. The cause of the decrease in growth-rate is probably a food shortage brought about either by overcrowding or by a change in the hydrographic conditions. (3) Marking experiments have shown an emphatic movement southward along the coast of fish which grew up in the north. This is apparently a new development and somewhat mystifying, particularly since the northern waters have hitherto, at least in recent years, shown as good or better conditions for the growth of the cod, when compared with the southern part of the coast. There is naturally an anxiety, fostered also by short cold reversions in the climate during the past few years, that this phenomenon may have some connection with a weakening of the influence of the Atlantic water.

Other fishes: The Atlantic halibut, the arctic halibut, Greenland shark. arctic char, herring, redfish, catfish, and lampsucker are all used to a greater or lesser extent commercially or for local consumption. Recently Jørgen Nielsen joined the staff of the Greenland Fishery Investigations to work on the arctic char and the herring.

The Greenland shark, *Somniosus microcephalus*, has been fished in Greenland since the beginning of the nineteenth century, the oldest fishery in the country. Dr. Hansen has recently reviewed the fishery and what little is known of the biology of this remarkable fish in an article (1953) in the new

journal *Grønland*, published in Copenhagen. It is essentially an arctic rather than a subarctic fish, although found also in the Subarctic, and it is becoming less abundant in west Greenland, especially in the southwest, as a result of the warming of the marine climate in recent decades. It is still important north of Disko Bugt, and it is probable that the population has increased on the Canadian side of Baffin Bay owing to this northward movement into water of more arctic origin; but since the Canadian Eskimo have never used the shark, this must remain conjecture for the time being. It is an interesting and unexplained fact that the vitamin A content of the liver oil of the Greenland shark is always higher in arctic water; higher in east Greenland than in west Greenland, and higher in the northern part of west Greenland than in the southwest.

The value of the shark is not inconsiderable. In 1948 it was worth a little over one million kroner (Danish) to the Greenland economy, and the value of the Norwegian shark fishery in east Greenland was five times as great. The Norwegian shark fishery is pursued mainly in the Denmark Strait area, where it is now more important to the Norwegians than the hooded seal hunt.

Shrimp: The deep-water shrimp, *Pandalus borealis*, is growing in economic importance in Greenland; new trawling grounds have been found, and a new cannery has been built at Narssaq in the Julianehaab district. Erik Smidt is engaged in a study of the biology of the shrimp in Greenland, and has taken a leading part in the exploration for new grounds. In 1951 trawling experiments in Godthaab Fjord gave poor results in the Kugssuk channel and at Korkut; trawling in the Kapisigdlit area was more successful, but the production was nevertheless not large. Farther south, Kvanefjord gave poor results, but the experiments at Ivigtut were very successful, and the middle and outer parts of Igaliko Fjord also gave good results. These will give useful support to the new cannery at Narssaq, which is already being supplied from the trawling grounds in Skovfjord, Tunugdliarfik Fjord, and Lichtenaufjord, discovered some years earlier.

The shrimp stocks in the Holsteinsborg district were badly damaged by the low temperatures of the 1948–9 winter. Temperatures at the bottom of Amerdlok and Ikertok fjords dropped from about 1.5°C in the summer of 1948 to -1.5°C or lower in the summer of 1949. The temperatures are now back to the 1948 level, but the shrimp stocks are still small. The shrimp supplied to the Holsteinsborg cannery in 1949–50, a record year, came from new trawling grounds in Disko Bugt.

Zooplankton work at Narssaq: A student, Svend Haasted, went to Narssaq on a year's study of the biology of the Greenland shrimp in 1953, particularly to examine the planktonic stages, and the zooplankton in general. He planned to take regular quantitative samples of the plankton with Hensen nets in different depth ranges during a full twelve-month cycle; this will provide material for the study of the whole annual production cycle of the zooplankton in a subarctic area with ice-free water during the winter.

Marine biological station at Godthaab: The scientific station at Godhavn, established early in the present century by Morten P. Porsild, is well known. It has recently been taken over by Copenhagen University. The marine biological station at Godthaab, on the other hand, is quite new (1953), and is run by the Greenland Fishery Investigations under Dr. Hansen. In charge of it is Jens Kreutzmann, a young Greenlander who became interested in marine biology while still at school at Godthaab during the war (with the practical encouragement of the Canadian Consulate), and became assistant on board the research ship *Adolf Jensen* and at the Copenhagen headquarters, in the following years. The station will be occupied in the collection of information on fish and seal from the Greenland fishermen and hunters, and in the biological investigation of Godthaab and Ameralik fjords. From the marine biological point of view, it is ideally situated. Kreutzmann will also make quantitative routine plankton collections all year round at four stations in Godthaab Fjord and the surrounding waters, including phytoplankton samples taken with the Nansen bottle.

Seal: Marine research in Greenland has not hitherto paid much attention to the sea mammals. But the possibility of a return to colder marine conditions, which would increase the economic importance of the mammals at the expense of the fishes, and the general interest expressed internationally in such organizations as the International Committee for the Northwest Atlantic Fisheries (ICNAF), have directed the attention of the Danes to research on these animals in Greenland. Field research on marine mammals is not easy except at the breeding grounds, but it is planned to carry out investigations of census, migrations, and age composition on the seals of west Greenland, in cooperation with the Norwegian work in east Greenland and the Canadian investigations on the harp seals (*Phoca groenlandica*) in the waters of Newfoundland and the Gulf of St. Lawrence, and the ringed (*Phoca hispida*) and bearded seals (*Erignathus barbatus*), and walrus (*Odobenus*) in the Canadian Eastern Arctic.

Offshore research west of Greenland

All the marine work summarized above, except in Peary Land and Danmarks Fjord, comes within the operations of the Greenland Fisheries Investigations headed by Poul M. Hansen, and under the aegis of the Greenland Department. In the offshore waters of west Greenland, and also east of Greenland, hydrographic and biological work, with emphasis on the former, has been done and is being done by the staff of the Danish Fisheries and Marine Research Laboratory on board the Research Vessel *Dana*, and also by the Norwegians. The stations occupied by the *Dana* in 1950 and 1952, and by the Norwegian ship *Uran* in 1948, are shown in Fig. 1. The *Dana* sections are now routine, and most or all of them will be maintained every year in future. In 1953 the southernmost section southwest from Kap Farvel was extended as far as the Labrador coast. The usual physical and chemical parameters are measured at these stations, samples for the determination of the phytoplankton crop are taken, and mid-water trawls with such nets as

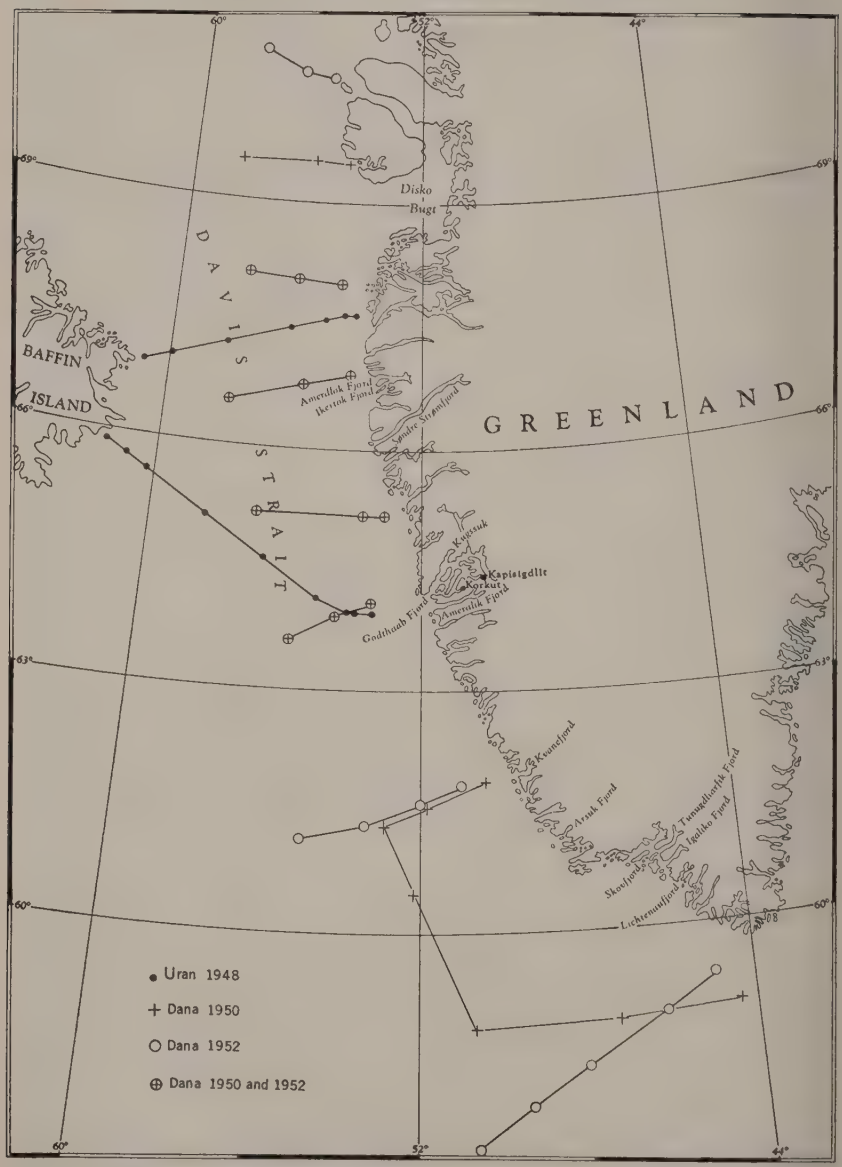

Fig. 1. Hydrographic and plankton stations in waters west of Greenland in 1948, 1950, and 1952. (From a drawing prepared by J. Grøntved).

the 2-metre stramin trawl are made. The value of this work can hardly be over-estimated, because it provides an annual record of hydrographic and biological conditions in an oceanographic region which is, at the present

stage in the postglacial cycle, peculiarly subject to oscillations, and which at the same time is of very great economic importance to man; and the economic importance depends on the climatic cycle to a great extent.

Fundamental to the economic value of the Canadian Eastern Arctic and west Greenland are the factors underlying the differences in, and variations in, organic production in the sea. Studies of the rate of production of organic material in the west Greenland waters have begun, and in the meantime the estimation of the standing crop of phytoplankton during the summer months is receiving special attention on the basis of samples collected by the *Dana*, the *Uran*, and the *Adolf Jensen*, which are being worked out by Julius Grøntved in the Plankton Laboratory at Charlottenlund Slot in Denmark. Quantitative phytoplankton investigations on the west Greenland banks were first made by the Norwegian biologist Gran (1929), and a recent manuscript report by R. W. Holmes deals with the annual cycle of the phytoplankton in the Labrador Sea (1950–1) based on weekly collections made on board the weather ship at Station Baker (56°30N., 51°00W.) Grøntved's work, however, which will be published in the *Meddelelser fra Danmarks Fiskeri- og Havundersøgelser*, will be of much greater scope than either of these studies, based as it is on quantitative collections during three seasons at the stations shown in Fig. 1, plus stations occupied by the *Adolf Jensen* in April and May 1950 and 1952 on the Fylla and Store Hellefiske banks.

In the preparation of this paper the writer was indebted to Dr. Poul M. Hansen, Magister Julius Grøntved, Dr. Erik Smidt, and Magister Christian Vibe for material on the work in which each is engaged, and in particular to Magister Grøntved for the map of the sections given in Fig. 1.

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ANOMALOUS DEVELOPMENT OF VITELLARIA IN HEMIURUS LEVINSENI (TREMATODA)

By Leo Margolis

In the course of a survey of the parasites of North Pacific salmon (genus *Oncorhynchus*), 218 specimens of *Hemiurus levinseni* Odhner (family Hemiuridae) were collected from the pink salmon, *Oncorhynchus gorbuscha*, of which 101 specimens were encountered in a single host. From this latter lot one trematode possessed three compact vitelline glands (Fig. 1), whereas the remainder displayed two, which is the normal number in *Hemiurus*, as well as in many other Hemiuridae. Only one hemiurid genus, *Thletrum*, characteristically possesses three vitelline masses.

Fig. 1. Anomalous *Hemiurus levinseni* from *Oncorhynchus gorbuscha*.

To the author's knowledge, this is the first report of the occurrence of an extra vitelline mass in a trematode.

The abnormal specimen, 1.53 mm. long (including the protruding portion of the ecsoma), is considered to be a young adult because of the comparatively small number of eggs in the uterus.

The host was an adult fish returning from sea to ascend the Fraser River, British Columbia, on its spawning migration and was taken in the commercial gill-net fishery at the mouth of the river on August 1, 1955.

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THE MARKING OF FISH

By

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USES OF MARKING ANIMALS IN ECOLOGICAL STUDIES: THE MARKING OF FISH

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Introduction

The origins of fish marking and tagging go back to a dim past, but the first carefully planned and successful tagging was done by C. G. Atkins on Maine salmon in 1873, according to Rounsefell and Kask (1945). For two decades afterward, tagging was principally a salmon-fisherman's hobby. Limited numbers of tags made of materials like silver and platinum were used. Marking of utilitarian fishes on a large scale began in Denmark in the 1890's; C. G. J. Petersen affixed tags to plaice and also punched holes in their fins.

Both tagging and mutilation have been widely used and have proved to be powerful tools for studying population ecology.

The qualifications of a perfect tag or mark would include the following:

(1) It should not affect the mortality rate or the behaviour of the fish, either immediately or cumulatively.

(2) It should make the fish neither more nor less liable to be captured by fishing gear, than are unmarked fish.

(3) It should identify the individual fish.

(4) It should be retained by the fish indefinitely and should be readily observed by those from whom recoveries are expected. (Also, it should preferably pass unnoticed by those from whom recoveries are *not* desired: in some types of experiment only recoveries made by special observers are of value, and prior removal of some tags by others is disturbing.)

Obviously it will rarely be possible to obtain a perfect tag or mark, meeting all the above requirements. For many purposes one or more of them are unnecessary, or can be relaxed with little loss of information. Good design in marking experiments consists of choosing the tag or mark most appropriate for the end in view and for the means of recovery available, and then in making certain that the recovery procedure does in fact operate efficiently.

Marking by Mutilation

By far the most popular mark for fishes has been the removal of one or more fins—wholly or in part. Though this procedure does not permit recognition of individual fish, except in small-scale experiments, it is often accomplished with less injury to the fish than tagging involves, and can be used on smaller individuals. For short experiments, instead of removing a whole fin only a part of it may be cut off, or a hole may be punched in it.

Before starting a marking experiment, it is usually desirable first to sample the population for natural incidence of the mutilation proposed. In salmonids, for example, this incidence is sometimes high enough to be disturbing when single fins or both fins of a pair are used, *and* when only a small fraction of the total stock will be marked. If two unrelated fins are used, or if a fairly large fraction of the stock (say 1 percent or more) has been marked, natural mutilations are relatively so scarce as to be of little significance.

Regeneration must be tested in each experiment separately. In general, regeneration seems to be more common or more complete among spiny-rayed fishes than among soft-rayed fishes, among small fish as compared with large fish, and in warmer as compared with cooler waters. Also, median fins tend to regenerate more quickly and perfectly than paired fins, and the closer a fin is cut, the less the likelihood of regeneration.

Quantitative recovery of fin-clipped fish must be done by specially assigned observers, and it is desirable to have enough fish marked so that they are encountered frequently (at least one in 1000); otherwise attention of the observers tends to flag.

Tagging

Rounsefell and Kask (1945) have described and illustrated the kinds of tags used up to the early 1940's. Some of the more successful types are as follows:

1. The popular Petersen discs: two baffles attached by a wire or filament through the fish's body, gill cover, or fin.

2. Cattle-type strap tags and similar bands or rings, clamped around the mandible, maxilla, or operculum. Relatively few fish retain these types of tag for long periods, and some shed them very quickly. However opercular straps on halibut, and rings around the maxillary of lingcod, have been recovered after many years (Thompson and Herrington 1930; Hart 1943a).

3. Streamer-type tags, usually attached by wire or nylon through the body or fin base, and with a metal disc or a "hydrostatic" cylinder trailing behind. For short experiments with very small fish, simple colored threads strung through the base of the dorsal fin have proved useful.

4. Internal tags, put into the body cavity: these are made of bright-colored plastic for recovery by hand, or of metal if recovery is to be by magnet or induction detector. There have also been recent trials with radioactive cobalt internal tags.

5. Recently in California, hollow plastic tubes have been threaded through the bodies of ocean fishes (Wilson, 1953). They have given the first satisfactory recoveries from Pacific tunas and work well with some other fishes.

In choosing a tag, the most important consideration is whether or not the fish can be individually inspected for recoveries. If not, mechanical recovery by magnet, induction coil or radiation counter is necessary. In general, this has proved more expensive and less satisfactory than individual recovery—so much so, that in a borderline case it might be desirable to inspect individually a rather small fraction of the catch and increase the number of tags put out as much as feasible. The fraction of the catch inspected

ıould of course be a known one, and so far as ossible a random one.

Where untrained observers must make the re-aptures, a conspicuous tag is indicated. Return f tags can be encouraged by publicity, by fre-uent visits from a collector, and by cash re-ards. In this way very substantial percentages f strap tags or Petersen tags, for example, have ften been returned. To check on the efficiency f this type of recovery it is desirable that *a ortion* of the catch be inspected by trained per-onnel, if this is at all feasible.

Most difficult of all to assess, usually, are the ate of loss of tags from the fish, and the effects f tagging or marking upon the mortality rate nd catchability of the fish. However, much in-enuity has been used in getting information on ıese matters, even with so difficult a subject as he wide-ranging California sardine or pilchard Clark and Janssen 1945; Janssen and Aplin 945). Sometimes apparently minor changes in rocedure make for important improvements in ecovery rate. For example, the tightness with vhich strap or Petersen tags are affixed can seri-usly affect their staying power, snug attachment eing unfavourable (Hart 1943a; Manzer 1952).

Holding fish in enclosures will often shed light n immediate mortality or tag loss, but it is less useful as a quantitative index of sustained mor-ality or loss. In removing fins from small fish, he immediate mortality from shock may be quite mall but the permanent handicap of a missing in in a dangerous environment may add up to a erious increase in mortality rate. With larger ish the immediate mortality is more likely to be mportant, particularly with species that are rought up from considerable depths or which in-ure themselves in the gear. However, with a uitable technique for tagging, in certain species, high degree of success has sometimes been chieved with little or no mortality of either sort.

Both in tagging and in marking, the use of seda-ives like urethane or sodium amytal can some-imes speed up the process and reduce injury or liscomfort to the fish.

Movements and Migrations

One reason for marking or tagging fishes is to earn about their movements. Examples of move-ıent over long distances always attract attention; ome of the more striking ones are shown in Fig-ıres 1 and 2.

The various species of tuna are at home in elagic waters of the warmer oceans. They have long been suspected of much traveling, and move-ments of bluefin tuna between the Mediterranean

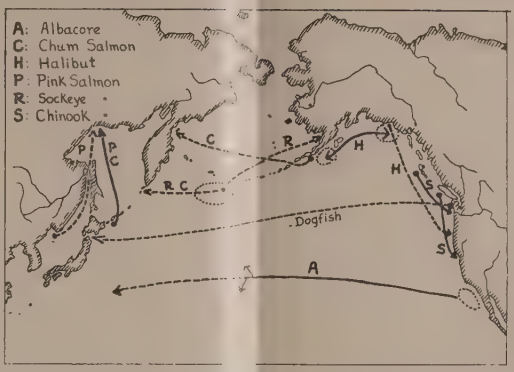

Fig. 1. North Pacific Ocean, showing fish movements as determined by tagging. Solid lines indicate frequent movements, dotted lines infrequent movements or those for which there is little information as yet. The lines do not necessarily indicate the paths followed by the fish. (After various authors.)

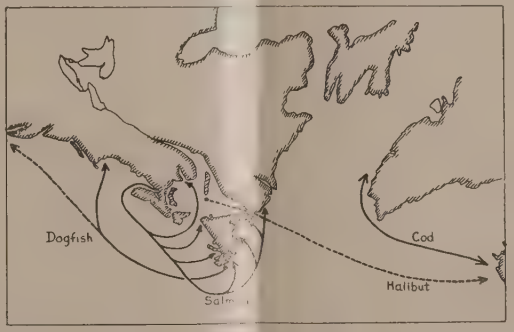

Fig. 2. "Side view" of the northwestern part of the Atlantic Ocean, showing frequent and infrequent movements of fish, as indicated by tagging or marking. The marked salmon shown came from the Petitcodiac River in the Bay of Fundy; there was also a similar distribution of smolts marked on the Miramichi. (After various authors.)

and the Atlantic were early recognized by means of hooks accidentally retained by and recovered from the fish. However few would have predicted the frequent transpacific crossings which are now suggested by preliminary results with albacore. Two have moved from California to beyond Midway Island, and one went 5300 miles to a point 550 miles SE of Tokyo in 10 months. (Blunt 1954; Ganssle and Clemens 1953.)

Though movements of tuna over thousands of miles were not unexpected, it came as a shock to learn that the homely shore-frequenting dogfish also is a great traveller. One individual was tagged at Willapa Harbour, Washington, and after 7½ years turned up in Tsugaru Strait, Japan (Kauffman 1955). The most direct distance is about 4400 miles, but the dogfish is likely to

have stayed fairly close to shore, so his total journey was probably at least as great as the albacore's. Other Pacific dogfish moved considerable distances along the American coast and, in the Atlantic, several went from St. John's Newfoundland, south to Massachusetts and even Virginia (Templeman 1954).

Though the above species are exceptional, many marine commercial fishes swim long distances. For example tagged Pacific halibut, though most frequently retaken within 100 miles of the point of tagging, apparently make fairly regular journeys across the south coast of Alaska, and a few individuals moved from that region down to the latitude of Washington or Oregon (Thompson and Herrington 1930). Similarly, halibut tagged in the Gulf of St. Lawrence nearly all were recaptured there, but one individual got as far as Iceland (McCracken, 1955).

For fishery management, the *typical* migration pattern rather than the exceptional event is of most interest. Metal tags recovered in reduction plants on the coast of British Columbia, during the 1930's, proved that the local body of California herring was an offshoot of the main body of California fish, which typically returned south each winter (Hart 1943b). The herring, by contrast, not only comprise a native population, but a number of rather distinct local populations have been distinguished and are regulated separately (Hart, Tester and Broughton 1942). In this case the populations had mostly already been distinguished by average differences in meristic characters; the tagging supplemented this picture and indicated the amount of interchange between populations.

The most striking demonstrations of individuality of populations have been with the various salmons. Clipping fins from a portion of the sockeye salmon smolts leaving Cultus Lake, British Columbia, had indicated a large number of returns to that spot. However the marked ones were found to be only two-fifths as numerous, proportionately, as the unmarked, suggesting the possibility of extensive "straying." Fortunately it was possible to mark *all* the smolts in two later years, and the returns from those years showed less than 1 percent straying (Foerster 1936). The poorer percentage of returns of marked individuals was evidently the result of a serious marking handicap.

Even when there is no chance of marking *all* smolts in an area, discreteness of populations can be proven somewhat indirectly. Figure 2 shows diagramatically how this was done for several Atlantic salmon stocks (Kerswill 1955). Marking of smolts in the Petitcodiac River and two branches of the Miramichi, in New Brunswick, yielded large numbers of returns in the commercial fisheries, particularly off Newfoundland. At the same time the marked fish returned abundantly to their home streams, but none at all were taken in the several Newfoundland streams examined. Nor were they seen in other New Brunswick or Quebec streams where search was made. Thus it was possible to obtain proof of substantially complete segregation of various river races, and their regular return from long distances—an often-disputed thesis, which nevertheless must be the cornerstone of Atlantic salmon management.

The whereabouts of Atlantic salmon during their sea life, before the spawning migration, has not yet been determined. In the Pacific, chinook and coho salmon can be caught just offshore, and tagging experiments during the 1920's indicated extensive movements down the coast (Clemens *et al.* 1939). The more abundant but more elusive pink, chum and sockeye salmon have not yet been followed in their journeys away from and back to the American coast. However, from the Asiatic side they were followed far out to sea during the 1930's by Japanese pelagic gill-netters, who have done a certain amount of tagging (Anon, 1955: see also Fig. 1).

Preliminary results suggest an area of mixture of Alaskan and Siberian stocks in the region of the western Aleutian Islands. To define more accurately the extent and importance of such mixture is one of the principal concerns of the recently organized International North Pacific Fisheries Commission. Brief mention must be made of the use of tags in fresh water to identify times and speed of migration, and reaction to obstacles. Some of the problems and results of this kind of work are given in papers by Thompson (1945), Ricker (1947), Talbot (1950) and Godfrey *et al.* (1954).

Movements of non-anadromous fishes in fresh waters studied by Scott (1949) and Gerking (1953) have demonstrated that marked river fishes mostly stay in or return to the same "holes" for years at a time, being dislodged neither by spring freshets nor by the muddy torrents which follow summer cloudbursts. This is the more interesting because fyke-netting on the flood plain during high water showed that at least some of these fish did move out of the normal channel and fed on the abundant earthworms. Fishes brought in to a stream from outside are apparently much less likely to remain where they are put, though a well-controlled comparison has not yet been made. Trout displaced from their original homes in a small river tended to move back to them (Miller

1954). In lakes, similarly, release of tagged fish where they were caught has often been followed by recaptures predominantly in the same place: an early example is an experiment on pike by McKenzie (1930). Also, when fishes in a small lake are marked and moved to a part of it other than their "home," most species show considerable ability and inclination to return to the original site (Ball 1947; Shoemaker 1952).

Growth, Survival, Exploitation and Abundance

For most fishes the most important use of tagging and marking has been to help estimate the vital statistics, or biological statistics, of their populations. Treatments of suitable methods and computations have been given by Ricker (1948) and by Rounsefell and Everhart (1953).

Growth. Growth of fishes is estimated mainly from marks on scales, otoliths or bones. However, the observed growth of tagged fish after a year or more of freedom can provide a check on accuracy of other methods, particularly for larger fish where ages from scales or otoliths tend to be uncertain. Because some kinds of tags have been found to slow up the fish's growth, the method must be used cautiously.

Survival rate (s). When rate of fishing is constant from year to year, recaptures (R) of marked individuals in successive years are used directly to estimate survival rate; i.e., $s = R_2/R_1$. Such an estimate is not affected by any temporary hardships of the tagging or marking procedure, provided some interval is allowed for recuperation before the first year's recoveries begin. If rate of fishing varies from year to year, this can be taken into account for survival estimates. Possible procedures are to mark fish in two successive years, or to use information on the level of fishing effort which prevailed (formulae 39 and 38 of Ricker, 1948).

Survival estimates obtained as above are usually used to check estimates made from the age distribution of the population. Most of the potential sources of error are different in the two methods so that, when they agree, the result can be treated with considerable confidence.

Rate of exploitation (u), *and population* (N). The fraction of fish removed from a population by a fishery is the basic datum for all management procedure. Usually only marking experiments can supply it directly. The simplest situations are very simple indeed: a representative body of fish (M) is marked just before the fishing season, and that year's recaptures (R) are tabulated, so that $\hat{u} = R/M$. Further, if total catch (C) is known, the vulnerable population of fish is estimated as $N = C/\hat{u} = CM/R$. This last is commonly called the Petersen formula, and it will probably long be used; however maximum likelihood has indicated an alternative form, $N = M(C+1)/(R+1)$, which is appreciably more efficient when recoveries are few (Bailey 1951).

Unfortunately few real experiments are this easy. Often it is impossible to mark fish quickly just before a fishing season, and in that event their natural mortality prior to fishing must be accounted for. If marking and recovery both extend through the fishing season, the Petersen method must be elaborated into a "Schnabel" or other similar estimate. For a variety of reasons there may be unrepresentative recoveries—either too many or too few—during the first few days, weeks or months of an experiment. For example, Chatwin (1953) describes serious potential sources of error in what seemed at first sight to be a straightforward piece of work. An important and often ignored complication in long-term experiments is a change in vulnerability of the fish as they grow older; or the vulnerability of all fish may vary from year to year. Most of the varied procedures which have been proposed to adjust for the above systematic biases are discussed in one or both of the general works cited at the beginning of this section.

A different method of treating a large-scale marked fish experiment is to relate the recoveries per unit of fishing effort to cumulative catch throughout the fishing season, and from that to compute survival, catchability and rate of exploitation. DeLury (1951) proposed this as a modification of the Leslie method (which does the same thing with unmarked individuals) mainly in order to check the assumptions on which the latter depends. Under favorable circumstances, however, differential response of the marked and the unmarked can be interpreted in terms of emigration from and immigration into the stock, and can be used to estimate these effects quantitatively (Ketchen 1953).

Summary

Since the 1870's, fish have been marked by affixing tags and by removing fins. Recaptures are used to indicate movements and migrations, discreteness of populations, rate of growth, overall mortality and survival rate, rate of exploitation by a fishery, natural mortality rate (by difference), and actual population size. Quantitative information from marking is rendered uncertain by possible systematic biases of varied types. However, reliable results have sometimes been achieved by

careful selection of the most suitable tag or mark, combined with a recovery program of tested efficiency.

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OLFACTORY PERCEPTION IN MIGRATING SALMON

I. L-SERINE, A SALMON REPELLENT IN MAMMALIAN SKIN

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(Received for publication, January 25, 1956)

The presence of a repellent for migrating coho (*Oncorhynchus kisutch*) and spring (*Oncorhynchus tshawytscha*) in the skin of salmon predators has been previously reported (1). The repellent was estimated to be active at a concentration of one part in at least several million parts of water. This is not surprising in view of the known ability of minnows to respond to the presence of a dead member of the species when the active material is present at a concentration of the same order of magnitude. In this case the active substance has not been identified but has been suggested to be a purine or pterin (2, 3).

It has been demonstrated that it is a result of keen olfactory perception that salmon are able to return to the parent stream (4, 6). Catfish (*Ameirus*) and killifish (*Fundulus*) have been shown able to detect food solely by olfactory response (7, 8). Because of the very low threshold of activity, it is most probable that the response of salmon to the repellent in mammalian skin is also elicited by way of the olfactory mechanism (1).

Several synthetic substances were tested for salmon repellent activity, some because they are normal components of skin and some for other reasons, but all were found to be inactive (1). When migrating salmon ascending a fish ladder were exposed to the active substance upstream movement was halted for at least 5 minutes and sometimes considerably longer. The fish displayed an alarm reaction characterized by rapid movements confined to a pool of the ladder and on some occasions the fish retreated to a lower level. The next phase involved a keen alertness during which time slight disturbances in the water which normally evoked no reaction caused immediate response. Finally, the "danger" past, the fish resumed the ascent in a normal manner.

A rinse of human hands has now been shown to contain a repellent for all five species of migrating salmon found in Pacific northwest coho, spring, chum (*Oncorhynchus keta*), sockeye (*Oncorhynchus nerka*), and pink (*Oncorhynchus gorbuscha*). In an effort to find a source of sufficient quantity for identification studies, samples of seal and sea-lion skin were ground in a Waring blendor and

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thoroughly extracted with water. In neither case was the extract significantly more active than a thorough rinse of the same area of intact skin. Similarly successive human hand rinses showed diminishing activity. The active repellent is therefore a secretory product possibly associated with sweat. For this reason all work is now being carried out on hand rinses.

Hand rinses were prepared by submersion of the hands for 2 minutes in a convenient quantity of water (*i.e.* 1 liter). Prior to preparing extracts from hair-seal and sea-lion, the skin was freed from fatty tissue and hair. All instruments were thoroughly washed in running water, and rubber gloves were worn by the investigators. The samples were introduced into the water at the fish ladder from waxed containers. Each extract was prepared from 25 gm. of skin and made up to a final volume of 265 ml. Aliquots were taken and the solution introduced into the water entering the top pool of the fish ladder. Testing was carried out at Stamp and Skutz Falls on Vancouver Island as previously described (1). Since satisfactory testing conditions are limited to a brief period in the fall of the year, many additional suspected or known components of skin were tested for activity while the isolation work was proceeding. These included phosphate esters, sugars, fatty acids, purine and pyrimidine compounds, enzymatically hydrolyzed casein, and many others. All compounds were inactive.

To determine the ion exchange properties of the repellent dialyzed washings from human hands were concentrated to *ca.* 50 ml. and passed through beds of resin 1 inch × 12 inches. The bed was then washed with 3 volumes of distilled water and the eluate tested for activity. One of each class of strong acid, weak acid, strong base, and weak base resin was tested. The resins were conditioned to either the hydrogen or hydroxyl form prior to use. The repellent was bound only by strongly acidic and strongly basic resins. The active component of human skin, seal-skin, and sea-lion skin is water-soluble and partitions into the aqueous phase from diethyl ether and *n*-butanol. It is stable to prolonged soxhlet extraction and is not destroyed at pH 2 or 11 on standing 2 days at room temperature. The repellent is not steam volatile nor is it destroyed by this treatment, neither is it volatile at 25 mm. Hg. on a boiling water bath. It is dialyzable. Activity is not destroyed by a wide variety of proteolytic enzymes. Dialyzed concentrates have been stored in the frozen state for many months without loss of activity.

A Shandon continuous paper electrophoresis apparatus equipped with side electrodes was employed to further purify the repellent. A 3 mm. Whatman paper was used and the distance from the wick to the top of the serrations was 12 inches with a paper width of 17 inches between electrodes. The apparatus was operated at 520 to 540 volts at a current of 10 ma. The wick was a $\frac{1}{8}$ inch strip of Whatman 3 mm. paper which entered the paper $\frac{1}{2}$ inch below the top of the electrode and was positioned over tube No. 7. Ten hand rinses were collected in 2 liters of water from the same investigator at 20 minute intervals.

The washings were concentrated to 100 ml. at 40°C. in the flash evaporator and the concentrate was dialyzed for 68 hours against 3 liters of water at +1°C. The dialysate was concentrated to *ca.* 0.25 ml. on a flash evaporator and made up to 5 ml. with 0.4 M acetic acid which was also used as the developing electrolyte. The volume in each of the 30 collecting tubes was approximately 5 ml. The α-amino nitrogen distribution in the contents of the tubes was measured colorimetrically with ninhydrin employing a valine standard (Fig. 1). Total nitrogen in the active fraction, measured with the Nessler reagent, was in general agreement with values obtained by the ninhydrin re-

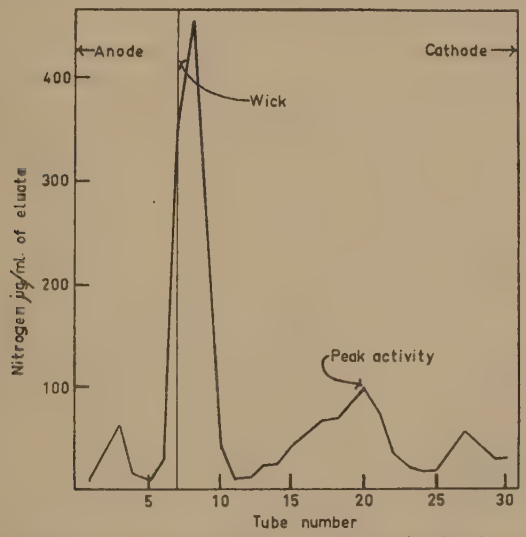

FIG. 1. Continuous paper electrophoretic nitrogen distribution of hand rinses described in text.

agent. Repetition of the experiment resulted in activity occurring in the same fraction and a dry weight determination showed that amino acids accounted for nearly all the total solids in these fractions.

Paper chromatograms were run on the active fraction from continuous paper electrophoresis. Solvent systems used were pyridine-H_2O (acetic acid vapor); *tert.* butanol-formic acid; phenol-water, and butanol–acetic acid–water. Serine was identified as a major component of the active fractions. Four other ninhydrin-positive compounds were present, three of which were identified as valine, leucine (or isoleucine), and cystine. A compound which runs close to serine in several solvents has not yet been identified. In preliminary tests carried out at the fish ladder *l*-serine was active at a dilution similar to the estimated concentration of the natural repellent. The *d*-isomer showed no

activity. The *l*-isomers of the other identified, as well as closely related amino acids, were inactive. Before further tests could be carried out the water levels had become excessive at the fish ladder. A run of coho was located at Sweltzer Creek, near Cultus Lake, British Columbia. The fish were fighting a strong current, and testing conditions were good. The tester, wearing rubber hip boots, stationed himself just upstream from a sandbar which formed an obstruction making it necessary for the salmon to pass through a narrow opening about 2 feet deep. Two observers were stationed several yards downstream. When the fish (usually about 20) reached the constriction the material to be tested was introduced upstream. A hand rinse immediately scattered the salmon back downstream and they returned in *ca.* 5 to 10 minutes. *l*-Cysteine, *l*-leucine, *l*-isoleucine, *l*-valine, *l*-methionine, and *l*-cystine were all inactive when introduced at levels of 10, 5, 1, and 0.5 mg. per 180 ml. of water introduced into the stream. *l*-Serine was tested several times on different days and the results confirmed the finding obtained at the fish ladder. *l*-Serine definitely elicited a typical alarm reaction but the effects were neither so dramatic nor of so long a duration as the response obtained by a hand rinse. However, *l*-serine was active at extreme dilution which we estimate to be of the same order of magnitude as the natural repellent.

The ability of salmon to detect an odour from predators has very obvious survival value. In addition, such a salmon repellent has considerable potential value in deterring salmon from physical barriers and polluted waters. Used in conjunction with attracting stimuli, salmon could be directed to an alternative course around obstacles to migration imposed by increasing industrial developments and uses of natural waters.

Work is continuing in an effort to obtain a purified preparation with as much activity as a hand rinse.

SUMMARY

The properties of a repellent for migrating salmon present in mammalian skin are discussed. *l*-Serine which is present in the washings of human skin has been shown to have repellent activity at extremely high dilution.

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SOME PRINCIPLES IN THE THERMAL REQUIREMENTS OF FISHES

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INTRODUCTION

THE tissues of a fish, permeated by the network of the circulatory system, are constantly being brought into equilibrium with the external temperature at the gill surface. The high specific heat of water, which efficiently buffers the aquatic climate from the extremes of aerial conditions, has chained the gill-respiring vertebrate to a cold-blooded existence. To achieve regulation of body temperature requires control of the temperature at the respiratory surface or of the circulatory fluid, as well as of the body tissues. Insulation of the gills by means of fat deposition would defeat their primary purpose for oxygen uptake. Alternatively, the energy exchange required to bring the volume of water necessary for adequate respiration up, or down, to a satisfactory body temperature would frequently be exhausting. Evaporation, the chief physical aid for heat loss in an air-breathing vertebrate, is denied the gill-respiring vertebrate; adaptations to an aquatic life leave it entirely subject to the variations of environmental temperature. Measurements of the body temperature of fish and other aquatic poikilotherms confirm this relation, the equilibrium state being reached more rapidly among small than large forms (S. Simpson, 1908; Pearse and Hall, 1928; Nielson, 1938; Gunn, 1942; Davis, 1955).

Minor exceptions may arise through heat production from excessive activity, particularly for a fish caught by some means which prevents normal respiration, or through the rapid excursion from one level of thermal stratification to another (Morrow and Mauro, 1950). At near-lethal, low temperatures the effect of greatly reduced respiration may permit body temperatures to be temporarily maintained above that of the environment. Measurements of the stomach temperature of brown bullheads (*Ameiurus nebulosus*) when taken from 20°C. and placed in ice-water showed an internal temperature of 0.3° to 0.5°C. above the external temperature after two hours of immersion. (Previously unreported observations made at the Ont. Fish. Res. Lab., Algonquin Park, Ont.)

Lacking a means of maintaining an independent body temperature, the aquatic poikilotherm may be a victim of rapid internal temperature change caused by sudden changes in environmental temperature. The response of many fish when plunged into relatively cold water is one of violent bursts of activity followed by benumbed inactivity. Such a temperature change, although acting as a strong stimulus, simultaneously depresses the animal into temporary dormancy. The conflict of combined stimulation and depression is quite striking. Because of the all-pervading nature of environmental temperature, the fundamental thermal requirement of fishes is an *external* environmental temperature most suitable to their

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internal tissues. That this temperature may not be limited to a matter of a few degrees attests the extent to which the poikilotherm has been able to evolve bodily functions which can maintain adequate roles *despite* variation in body temperature (cf. Bullock, 1955).

Temperature sets lethal limits to life; it conditions the animal through acclimation to meet levels of temperature that would otherwise be intolerable; it governs the rate of development; it sets the limits of metabolic rate within which the animal is free to perform; and it acts as a directive factor resulting in the congregation of fish within given thermal ranges, or movements to new environmental conditions. Some of the principles in this multiple role of temperature will be considered.

LETHAL LIMITS

Upper and lower lethal temperatures

The upper and lower limits of temperature which fish can withstand define the extremes of tolerable thermal environment. While a variety of experimental procedures have been used to determine the lethal limits (Loeb and Wasteneys, 1912; Hathaway, 1927; Fry, Brett, and Clawson, 1942; Doudoroff, 1942), in each case an effort has been made to provide a simple index, usually expressed as the mean or median temperature tolerance for an unselected sample of fish when exposed for some predetermined interval of time. A number of distinct characteristics of the lethal temperature have been repeatedly demonstrated. Under carefully controlled conditions the upper lethal temperature is remarkably precise. It can be determined consistently in many species to within ± 0.2°C. This sensitivity has permitted a comparison of species tolerance, with significant differences obtained between closely related species (Brett, 1952) and some subspecies (Hart, 1952). Indeed, Gibson (1953) has obtained data which suggest that temperature resistance in the guppy (*Lebistes reticulatus*) can be affected by selective breeding. In addition, species which show similar upper lethal limits may be characterized by quite different lower levels of tolerance. The order of temperature resistance (heat-tolerance) among eight species of freshwater fish from Algonquin Park lakes, Ontario, was reversed for half these species when they were tested for cold-tolerance (Brett, 1944).

The lethal limits are only consistent within a species when repeated for fish from similar acclimation temperatures and cultured under comparable conditions (cf. Hoar and Cottle, 1952a; Gibson, 1953). As the temperature of acclimation increases, so the lethal temperatures progressively increase. For the goldfish (*Carassius auratus*) Fry et al. (1942) report that for every 3°C. rise in acclimation temperature the rate of change of the upper lethal temperature was about 1°C., and that for the lower lethal temperature nearly 2°C. A considerably lesser rate of change was obtained for yearling speckled trout (*Salvelinus fontinalis*), which required a 7°C. change in acclimation to produce a 1°C. change in the upper lethal temperature (Fry, Hart, and Walker, 1946). The rate of increase is not constant throughout the full range of acclimation, but usually "levels off" to zero in the region of relatively high acclimation for each species. The fact that the lethal temperatures are subject to change through acclimation has led to the calculation of the area enclosed within upper and lower lethal ranges, for temperatures of acclimation from 0°C. to the maximum for any given species (Fig. 1; Table 1). This defines the *zone of tolerance*, with the unit of tolerance equal to the area bounded by 1°C. (expressed as "degrees Centigrade squared"). The extent of eurythermicity of the organism

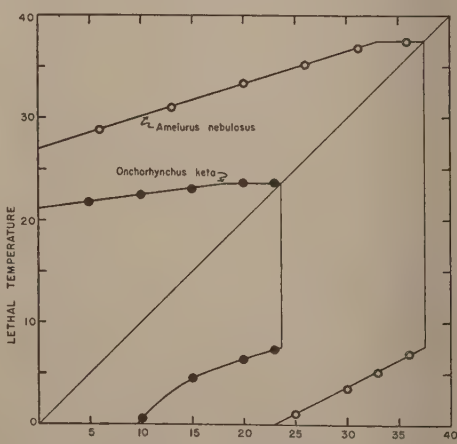

FIG. 1. LETHAL TEMPERATURE RELATIONS FOR TWO SPECIES OF FISH

The bullhead, *Ameiurus nebulosus*, is a highly tolerant species in contrast to the chum salmon, *Oncorhynchus keta*, which is one of the least resistant studied to date. The area enclosed by each trapezium is the *zone of tolerance*. (Data from Brett, 1944 and 1952).

TABLE 1

Lethal temperatures and thermal tolerances of various species of fish arranged in order of thermal tolerance

Species	Family		Upper (U.) and Lower (L.) lethal temperatures for acclimation temperatures of:						Thermal tolerance	Habitat	Reference
			5°C.	10°C	15°C	20°C	25°C.	30°C			
*Oncorhynchus gorbuscha**	Salmonidae	U.	21.3	22.5	23.1	23.9			450‡	Cool streams	7
		L.									
*Oncorhynchus keta**	Salminidae	U.	21.8	22.6	23.1	23.7			468	Cool streams	7
		L.		0.5	4.7	6.5					
*Oncorhynchus nerka**	Salmonidae	U.	22.2	23.4	24.4	24.8			505	Cool streams, deep lakes	7
		L.	0.0	3.1	4.1	4.7					
*Oncorhynchus kisutch**	Salmonidae	U.	22.9	23.7	24.3	25.0			528	Cool to moderately warm streams and lakes	7
		L.	0.2	1.7	3.5	4.5					
*Oncorhynchus tshawytscha**	Salmonidae	U.	21.5	24.3	25.0	25.1			529	Cool streams	7
		L.		0.8	2.5	4.5					
Salvelinus fontinalis	Salmonidae	U.	23.7†	24.4†	25.0	25.3	25.3		625	Cool streams, deep lakes	4
		L.					0.5				
Perca flavescens	Percidae	U.	21.3	25.0	27.7		29.7		742	Deep and shallow lakes	5
		L.		1.1			3.7				
Notropis atherinoides	Cyprinidae	U.	23.2	26.7	28.9	30.7	30.7		747	Shallow lakes, cool streams	5
		L.			1.6	5.2	8.0				
Catostomus commersonni	Catostomidae	U.	26.3	27.7	29.3	29.3	29.3		770	Shallow lakes, warm and cool streams	5
		L.				2.5	6.0				
Rhinichthys atratulus	Cyprinidae	U.	26.5	28.8	29.6	29.3			790	Warm and cool streams	6
		L.				2.2					
Girella nigricans	Stromateidae	U.		28.7		31.4		31.4	800	Shallow marine bays and pools	2
		L.		5.0		8.0		13.0			
Notropis cornutus	Cyprinidae	U.	26.7	28.6	30.3		31.0	31.0	803	Shallow northern lakes. Cool and warm streams	5
		L.			0.0	3.7	7.8				
Semotilus atromaculatus	Cyprinidae	U.	24.7	27.3	29.3	30.3	30.3		808	Lake shallows, warm and cool streams	6
		L.				0.7	4.5			
Dorosoma cepedianum	Clupeidae	U.					34.3	35.9	880‡	Shallow, open water	6
		L.					10.8	14.5			
Hyborhynchus notatus	Cyprinidae	U.	26.0	28.3	30.6	31.7	33.3		884	Shallow lakes, slow streams	5
		L.			1.0	4.2	7.5				
Pimephales promelas	Cyprinidae	U.		28.2		31.7		33.2	903	Shallow lakes	5
		L.				1.5		10.5			
Lepomis machrochirus	Centrarchidae	U.			30.7	31.5		33.8?	910‡	Shallow lakes	6
		L.			2.5	5.0	7.5	11.1?			
Notemigonus crysoleucas	Cyprinidae	U.		29.3	30.5	31.8	33.2	34.7	940	Warm and slow, cool streams	6
		L.			1.5	4.0	7.0	11.2			
Micropterus salmoides	Centrarchidae	U.				32.5	34.5	36.4	965‡	Marsh and shallow reed beds	6
		L.				5.5		11.8			
Ictalurus lacustris	Ameiuridae	U.			30.3	32.8	33.5		970‡	Large rivers and warm lakes	6
		L.			0.0	2.5	6.0				
Gambusia affinis	Poeciliidae	U.			35.4	37.3	37.3	37.3	1110‡	Marsh, very shallow reed beds	6
		L.			1.5	5.5					
Ameiurus nebulosus	Ameiuridae	U.	28.6	30.2	31.8	33.4	35.0	36.5	1162	Marsh; shallow zone of lakes	3
		L.				−1.0	1.3	3.7			
Carassius auratus	Cyprinidae	U.	29.0†	30.8	32.8†	34.8†	36.6†	38.6†	1220	Very shallow water	1
		L.				2.0	6.0	9.0			

* Freshwater fry stage only.

† Estimate from graph by interpolation.

‡ Provisionary, pending more data.

References: (1) Fry, Brett, and Clawson, 1942; (2) Doudoroff, 1942; (3) Brett, 1944; (4) Fry, Hart, and Walker, 1946; (5) Hart, 1947; (6) Hart, 1952; (7) Brett, 1952.

can thus be readily determined. Hart (1947) ascertained the lethal effects of temperature for eight species of fish from the Toronto region and made comparisons with results reported elsewhere in the literature. Since then Hart (1952) has published further studies on lethal temperatures; and results on temperature tolerance in young Pacific salmon have been reported by Brett (1952). These data are summarized in Table 1. Some generalities can be derived.

The Salmonidae have the lowest thermal tolerance found to date, with maximum upper lethal temperatures barely exceeding 25°C. The sea-migratory forms (*Oncorhynchus*) have considerably less resistance to low temperatures than is indicated for the lake and stream-dwelling char (*Salvelinus fontinalis*); indeed the latter has a greater cold-tolerance than any species yet reported.

With the exception of the goldfish (*Carassius*), the Cyprinidae occupy a somewhat intermediate position, with thermal tolerances ranging from levels approaching but distinctly above the Salmonidae, the difference resulting more from a resistance to high than to low temperatures. Through acclimation, an upper lethal temperature exceeding 30°C. is achieved by most members of this family.

The thermal tolerances of the single members studied from the families Percidae, Stromateidae, and Catostomidae occur at the low end of the range for the cyprinids, whereas the two centrarchids are towards the upper end.

The Ameiuridae appear to occupy the top position among the most eurythermal, along with the goldfish. The common bullhead (*Ameiurus nebulosus*) is also particularly resistant to low temperatures.

Black (1953) has made a comparison of upper lethal temperatures for similar and closely related species studied in British Columbia with those from Ontario (Brett, 1944; Fry et al., 1946; Hart, 1947) and some parts of the United States (Hart, 1952). Although variations can be seen to exist, these cannot be entirely ascribed to different geographic locations, owing to slight differences in experimental technique and the question of exact acclimation temperatures. However, the general conclusions are essentially the same as established elsewhere. One recurring exception appears to exist in the case of the largemouth bass (*Micropterus salmoides*), which Hart (1952) also reported to show significant geographic differences. It would be of interest to culture eggs taken from these separate populations under identical conditions and to establish unequivocally the degree of inherent physiological difference.

Resistance times

The lethal temperature is theoretically conceived as that temperature which fifty per cent of a population could withstand for infinite time. Experimentally it is obtained by subjecting samples of fish to a series of temperatures, higher levels of which result in complete mortality of the sample. The period of tolerance prior to death is known as *the resistance time* (Fry, 1947a). By plotting the logarithm of the median resistance time (i.e., the resistance of the most representative fish) for each of a number of test temperatures, the points are seen to form a linear series, the slope of which is relatively consistent for most species of fish, despite very different levels of resistance (Fig. 2). In each case an abrupt change in slope occurs, marking the point of transition from *resistance* to *tolerance* and signifying that death from temperature as a primary cause has ceased. This temperature is the *incipient lethal temperature.*

By virtue of this resistance it is possible for fish to make excursions for limited times into temperature zones which would eventually be lethal.

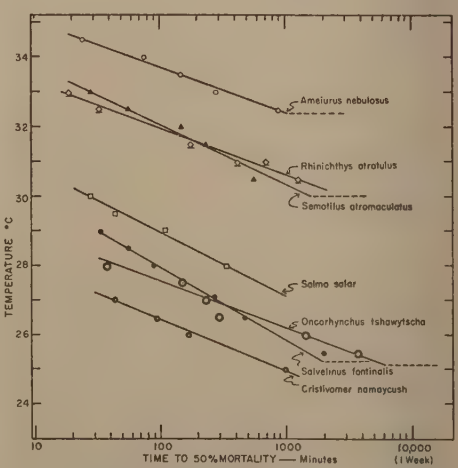

FIG. 2. MEDIAN RESISTANCE TIMES FOR SEVEN SPECIES OF FISH ACCLIMATED TO 20°C.
Broken lines indicate incipient lethal level. (Data from Fry, 1947b; Hart, 1952; Brett, 1952).

It also permits them to tolerate some diurnal fluctuations in which the peaks of environmental temperature actually exceed the lethal temperature (Fry et al., 1946).

Possible cause of death

The life of an animal can be maintained only in conjunction with the continuous functioning and integration of the majority of its tissues. The thermal lethal level must be set by the resistance of the most sensitive essential tissue. This tissue, for upper lethal temperatures, appears to be that of the nervous system. Freeman (1950) discovered that the metabolic activity of goldfish brain tissue approached zero at a temperature approximating the ultimate upper lethal temperature reported for this species by Fry et al. (1942). A pronounced depression, though not a cessation, in the rate of oxygen uptake of excised brain tissue from the largemouth black bass is reported to occur at 35°C. (Fuhrman, Hollinger, Crimson, Field, and Weymouth, 1944). The bass had been collected in a reservoir with surface temperatures ranging to 24°C. It is of interest that Hart (1952) obtained an upper lethal temperature of 34.5°C. for this species when acclimated to 25°C. In some fish the cause of death from high temperatures may possibly result from the inactivation of the respiratory center, followed by death from oxygen lack. The respiratory movements of the yellow perch (*Perca flavescens*) cease entirely with the approach of heat-death (Brett, 1944). Battle (1926) subjected muscle and nerve tissue of the skate (*Raja radiata* and *R. erinacea*) to gradual heating. Inactivation of the nerve tissues preceded that of the somatic and smooth muscles.

Death from intolerably low temperatures has also been attributed in some instances to failure of the nervous system. However, it is now known that thermal death may not always arise from the same cause. Doudoroff (1942) distinguished stages of "primary" and "secondary chill-coma" among samples of *Girella nigricans* when subjected to low temperatures. "Primary chill-coma" was not manifest until some seconds after immersion and apparently did not stimulate the cutaneous sense organs but penetrated to the central nervous system. A similar phenomenon was observed among young Pacific salmon (Brett, 1952). Experiments performed in saline solutions, slightly hypertonic to blood concentrations, indicated that three causes of death from low temperature were involved: one, a very rapid agent, usually effective within 60 minutes of exposure and probably a disturbance of the central nervous system; a second, which was related to osmotic balance; and a third, delayed in time of onset, and of unknown origin.

Peiss and Field (1950) studied the oxygen consumption of excised brain and liver tissues from the cold-adapted polar cod (*Boreogadus saida*) and compared these with similar studies on the warm-adapted golden orfe (*Idus melanotus*). The polar cod, obtained from waters ranging from −1.5°C. to +2.0°C., showed an ability to maintain a consistent rate of oxygen uptake of its tissues at all temperatures from 0°C. to 25°C. That of the orfe, although fairly similar for higher temperatures, was considerably reduced at levels below 10°C. In contrast, the period of sustained tissue respiration was progressively curtailed above 15°C. in the cod, whereas the orfe was capable of maintaining its uptake at all temperatures studied. In both cases the oxygen demand of brain tissue was greater than that of liver tissue. The authors concluded that the tissues of the polar cod were advantageously adapted to cold. Adjustment in the metabolic demand of the total organism to the appropriate climatic conditions has been studied by Scholander, Flagg, Walters, and Irving (1953). A comparison between some arctic and tropical fishes indicated that the cold-adapted forms were likewise capable of a higher rate of oxygen uptake at comparable low temperatures. When actively swimming, the arctic fishes expended a greater proportion of their available energy per unit time than did the tropical forms. That is, the routine act of locomotion is maintained much nearer the maximum level possible among arctic than tropical fishes at their respective normal environmental temperatures.

Hoar, in conjunction with Dorchester (1949) and later Cottle (1952a, b), has examined the effect of dietary fats of different melting points on the temperature tolerance of gold-fish, and made an effort to ascertain the nature of the thermal death of tissues. Although significant changes in resistance to high and to low temperatures were demonstrated, no direct relation between tolerance and the melting point of ingested fats was obtained. These authors believe that the integrity of the plasma membrane and its permeability is associated with the presence of unsaturated lipids in the structure of the membrane.

If the limiting tissue responsible for death from extremes of temperature is that of the nervous system, a critical examination of changes in this tissue separately is warranted.

Rate of acclimation

The varying ability among fishes to extend their temperature tolerance through acclimation has been illustrated. While the principle of acclimation, or more generally acclimatization (used synonymously with acclimation, cf. Bullock, 1955), has been recognized since the last century (Davenport and Castle, 1895), surprisingly little study has been devoted to this phenomenon. It would appear that the rate of increase in ability to tolerate higher temperatures among fish is relatively rapid, requiring less than 24 hours at temperatures above 20°C. (Doudoroff, 1942; Brett, 1944). Conversely, the loss in this increased tolerance, and the gain in resistance to low temperatures, are inherently slower processes, requiring up to 20 days in some species to approach completion. These rates appear to be governed by the rate of metabolism, which, if depressed by a low environmental temperature, automatically reduces the rate of acclimation. Whatever the process, Brett (1944) discovered that acclimation to a higher temperature in the bullhead was inhibited under conditions of low oxygen concentration.

It must therefore be a characteristic of at least the most sensitive tissue, or the integrating system (e.g., myoneural junction, nerve synapse), to be capable of rapid and reversible changes in temperature tolerance. Such a fish as the bullhead can increase its heat-tolerance by 10°C., whereas the speckled trout is limited to less than 5°C. Although fish lack a thermal control mechanism, their capability of inhabiting a wide range of thermal environments has been achieved by the development of remarkably tolerant tissues, and has been extended through acclimation. It is possible to culture goldfish over a range of 40°C. The homoiotherm has sacrificed this tissue tolerance, supplanted as it is by the considerably increased limits of tolerance to extremes of environmental temperature which thermal control has provided for the intact organism.

Ecological significance

There can be no doubt that the lethal temperature exerts limiting effects on the geographic distribution and freedom for successful existence in the confines of lake and stream, or the strata of the ocean. Fry (1951) has assembled much of the existing evidence for the environmental relations of temperature in the speckled trout (cf. Creaser, 1930; Ricker, 1934). The agreement between field and laboratory findings is convincing. Crises, when temperatures reach 24°C. to 27°C., can be survived only for short periods (Huntsman, 1946). However, the ability of fish to survive near-freezing temperatures is annually demonstrated in ice-covered lakes.

Somewhat in contrast to these are the temperature relations for six species of freshwater fish from lakes in Algonquin Park, Ontario (Brett, 1944). Seasonal changes in the upper lethal temperatures were determined for samples of fish from locations in which recording thermometers had been placed. In every instance the lethal temperatures rose rapidly with ascending lake temperatures, exceeding the daily lake maxima by 6° to 8°C. The highest seasonal lethal temperatures recorded for the six species ranged from 32°C. to 35°C., yet the full scope for temperature tolerance had not been tapped, as laboratory experiments revealed. The ability to exceed considerably the highest environmental temperatures to be expected in the common range of the species signifies that lethal relations must play a relatively unimportant role in the limiting of many hardy species, at least in the post-embryonic stage. Yet, in their general order of increasing heat-tolerance, they show a correlation with an ecological succession from cold streams and deep lakes to warmer streams and littoral zones, and finally to marsh conditions (Hart, 1952; Table 1, this paper). Some other property or attribute of the organism, roughly reflected by the upper lethal temperature, must be operating as the restricting factor to distribution.

Few cases of heat-death among fish are recorded in the literature (Bailey, 1955). Cold-death, however, has been reported more frequently (Verril, 1901; Storey, 1937; Gunther, 1941; Galloway, 1941). Although the threat to existence appears to come more from conditions of low temperature than of high temperature, the correlation between lower lethal temperatures and habitat is even less apparent than for upper lethal temperatures. This may be attributed in part to a characteristically slow rate of gain of cold-tolerance among fishes. It is the *rapidity* of the onset of low temperatures

that probably causes death, outstripping the ability of the fish to acclimate to a lower level, despite being within its biokinetic range.

Severe cold in the North Sea, as reported by A. C. Simpson (1953), appears to have exceeded the lower lethal temperatures for plaice, cod, whiting, and dab despite the probability that time did permit maximum acclimation. Nevertheless the author relates that "continuous cold easterly gales caused rapid cooling of the surface water." The lowest surface temperature recorded was −1.8°C. and a probable minimum bottom temperature of 0°C. (Vaux, 1953). The freezing point of the body fluids of teleosts lies mainly within a range of −0.5°C. to −0.9°C. (Dakin, 1912; Krogh, 1939; Kubo, 1953).

The state of thermal acclimation of the bullhead was traced by Brett (1944; 1946) from May to September in Lake Opeongo. The ability of this species to achieve a high level of acclimation as the environmental temperature rose rapidly in spring provided adequate safeguard for the high temperatures in the shallow reed beds of its habitat. As a result of the rapid acclimation to high temperatures, coupled with a slow loss of this recently acquired tolerance, acclimation kept pace with the daily lake water maxima.

The inability among young salmon to cope with osmotic stress at low temperatures would suggest that the estuarian conditions of moderate salinity would provide some sanctuary from cold-death.

DEVELOPMENTAL STAGES

As has been suggested, extremes of temperature can be withstood by many fishes to a degree which considerably exceeds the normal peaks of their environmental temperature; and habitat correlations with lethal temperatures are but grossly apparent. This applies only to the free-swimming, fully-formed fish. Precise knowledge of thermal tolerance and, more generally, the thermal requirements for the egg, developing embryo, and larval stages is scant (cf. Bonnet, 1939). There are inherent difficulties in determining the effects of temperature on an organism during a period of such rapid cellular change, particularly in the light of the importance of acclimation.

For animals in general, Baldwin (1948) comments that "at certain periods, notably at the time of gastrulation, the developing embryo is particularly susceptible to thermal and other changes." Battle (1929) discovered that the early blastodermic stages of the rockling (*Enchelyopus cimbrius*) were most susceptible to heat death. Abnormalities were produced by lowering the temperature of the ova to 5°C. Embody (1934) and Hayes (1949) have conducted research and reviewed much of the available information concerning the effects of temperature on salmonoid eggs. Interest has been centered on the incubation period and growth relations within a viable range of temperatures, embracing extremes of 1.5°C. (speckled trout) and 17.6°C. (rainbow trout). There is nothing to indicate that normal development is not possible throughout this span. The growth relation, however, shows some inconsistencies at the extremes. The theoretical relation of "*temperature* (°C.) × *time* = *constant*" applies quite well from 4 to 14°C. Deviation at lower temperatures would suggest that hatching is possible at 0°C. Embody, referring to the work of Dannevig (1894), notes that eggs of a marine fish, the cod, "were partly or wholly developed in sea water over a temperature range from −1 to +14°C."

Salmon and trout hatcheries are usually located near a natural source of cold, clear, running water. The necessity for low temperatures in artificial propagation, however, arises as much from avoiding disease under the unnaturally crowded conditions, as from obtaining a suitable temperature for development and hatching. Undoubtedly the migrations to cool, freshwater streams are necessary for the survival of the salmon species, from a thermal as well as an osmotic requirement. The embryonic stage of many coldwater fishes is passed during the winter and early spring, the fry emerging as the temperatures begin to rise. Relatively uniform low temperatures prevail. Pacific salmon (*Oncorhynchus*) eggs have been found to be viable under thin sheets of ice, locking the surface gravel like cement. When death occurs it has frequently been attributed to desiccation, oxygen lack, or disease rather than low temperature, although such a diagnosis is usually speculative.

It can be stated at least that the thermal requirements in the very early stages are more exacting than in the adult.

Ketchen (1953), while studying factors affecting the survival of the lemon sole (*Parophrys vetulus*) in Hecate Strait, B.C., discovered an inverse correlation between year-class strength and water temperature at the time of pelagic life. By relating

drift currents with temperature conditions in the Strait, the possibility of high temperatures so accelerating development that the young fish metamorphosed prior to reaching appropriate rearing grounds was demonstrated (cf. C. J. Fish, 1927; Walford, 1938). This interesting speculation exemplifies a more subtle limiting effect of temperature in combination with a second environmental factor.

Profitable comparison can be made with another cold-blooded vertebrate, the frog, from studies by Moore (1949) on some of the physical factors affecting distribution and survival in the genus *Rana*. In correlating adaptive differences with environmental temperatures, some of the main divergence among the species occurred in embryonic temperature tolerance and rate of development. The latter was greater at lower temperatures for species with a more northern distribution. This highly significant work on *Rana* points up the lack of such knowledge among other poikilotherms. Among amphibia in general McFarland (1955) has commented that "the effect of temperature acclimation on amphibians has been studied but little; in fact in the entire class little is known about lethal temperature limits."

A study of the stages in thermal requirements during development in fishes is sorely needed.

TEMPERATURE AND ACTIVITY

Death from temperature intolerance marks the ultimate breakdown in the organization of the individual. However, it is well recognized that feeding, resistance to disease, successful reproduction, and sufficient activity to permit existence in the face of competition and predation are all necessary for the continued maintenance of the organism. Within a population, inability to maintain any one of these activities at moderately extreme temperatures may be as decisive to continued survival as more extreme temperatures are to immediate life. Donaldson and Foster (1941) reported that when sockeye salmon fingerlings were gradually raised from 17.2°C. to 25.6°C. over a period of a week they "refused to eat and the respiration rate became excessive." By lowering the temperature to 21.1°C. feeding commenced and the fish "were able to make a very slight increase in weight." Water temperatures in the range of 4°C. to 7°C. produced poor growth. At a temperature of approximately 10°C., growth and food utilization were highest for the temperature conditions studied.

Adult salmon move inshore and upriver when maturing and spawn in freshwater streams. In doing so they must pass through water temperatures which may be far more extreme than those under which they finally spawn. F. F. Fish (1948) reported that during the summer of 1941 "the temperature of the Columbia River at Bonneville averaged 68.5°F. (20.3°C.). On July 20, 1941, the Columbia reached an all-time high temperature of 74.5°F. (23.6°C.)—hot water indeed for the blueback salmon (*Oncorhynchus nerka*), but a congenial temperature for certain of their microscopic enemies. One of these, the myxobacterium *Chrondrococcus columnaris* is particularly lethal to blueback salmon." The great losses in these salmon, almost obliterating the 1941 run, were attributed to the combined effects of high temperature and bacterial infection.

If the lethal temperature were directly related to other aspects of temperature and survival, in a like manner throughout species, it would constitute a very convenient index for a measure of the limitation of species. Lethal limits and the distribution of animals in temperature zones on the earth's surface would be in direct proportion, where temperature was the restricting factor. Frequently, such relations are but poorly represented. The crucial question appears to be what activity is possible in the region of the lethal temperature. If the ability to be active were not seriously limited at temperatures approaching the lethal level, such vital activities as feeding, competing, and migrating would still be within the powers of the animal up to that temperature. Slight increases in the temperature tolerance of the species would increase the possibility for greater environmental experience, and consequently be of survival value. Conversely, where the activity of the animal was restricted in the region of its lethal temperature, an increase in tolerance without an increase in the scope for activity would confer comparatively little survival value.

The work of Fry (1947a, b; 1948) and of Graham (1949) illustrates the points of this proposition. Fry (1947a) has reported the active and standard metabolism of the bullhead (*Ameiurus nebulosus*) at various temperatures ranging from 2°C. to 35°C., and bordering on the ultimate upper lethal

temperature for this species (about 37°C.). The difference between the active and standard metabolic rates at any given temperature is taken to be a measure of the scope for activity, the lower level of metabolism being ascribed to the energy required to maintain the animal when inactive. In this species the scope for activity increases with increasing temperature over the complete biokinetic range. The bullhead seems limited only by its ultimate upper lethal temperature rather than by any loss in available energy for activity. The speckled trout, however, reaches a peak scope for activity at about 19°C. (Fry, 1947b; Graham, 1949). Increasing temperature above this level results in decreasing ability to be active, down to a relatively low scope when approaching the ultimate upper lethal temperature. The bullhead is quite understandably a successful fish in the high temperatures of shallow lakes and inshore reed beds, whereas the speckled trout, although capable of withstanding a temperature as high as 25°C., is not likely to succeed in this environment.

Activity has also been measured by the speed at which fish can swim steadily in a rotating chamber (Fry and Hart, 1948). A relation between this measure of activity and that from a difference in standard and active metabolic rates was established for the goldfish (Fry, 1947a; Fry and Hart, 1948). A most appropriate work in this field on salmonoids was that reported by Fry (1948) for two chars, *Salvelinus namaycush* and *S. fontinalis*, and two trouts *Salmo gairdneri* and *S. trutta*. Yearling fish of the various species were compared with respect to scope for activity by both the above methods at temperatures ranging from 5°C. to 25°C. Fry (1948) commented that "although it is not certain that the difference between trouts and chars has a phylogenetic basis, these two groups show a striking difference in their *swimming-rate* versus *temperature* curves." The trouts both appeared to be capable of increasing activity up to their ultimate upper lethal temperatures, whereas the chars showed a reduction in activity as the temperature approached the lethal level.

If this relation of activity to temperature has survival value, cases in which similar or nearly similar lethal temperatures exist, accompanied by dissimilar peaks for maximum activity, might be expected to have different distributions according to temperature, under otherwise relatively

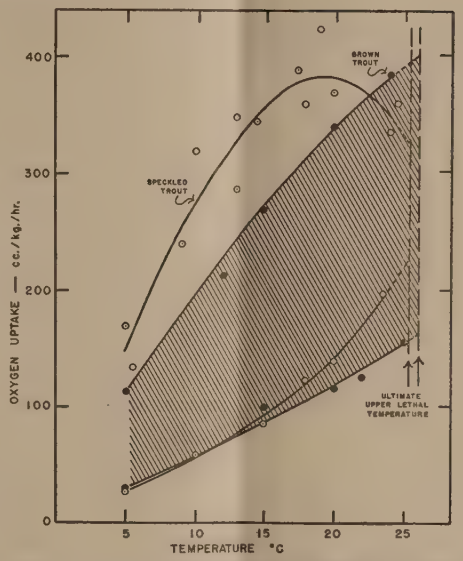

FIG. 3. THE RELATION BETWEEN TEMPERATURE AND METABOLISM FOR TWO SALMONIDS

The metabolism for speckled trout, *Salvelinus fontinalis*, and brown trout, *Salmo trutta*, has been measured as the active (upper) and standard (lower) levels of oxygen uptake when previously acclimated to each given temperature. (Data from Fry, 1948; Graham, 1949).

similar habitat conditions. The case of the brown trout and speckled trout appears to fall in this category (Fig. 3). King (1943) recorded that the brook or speckled trout is "considered a 'headwater' form and usually occurs in the upper stretches of trout streams," whereas the brown trout occupies "a position in the stream as a rule below that of the brook trout, but usually with an overlapping of ranges." Such a relation is supported by the work of Holton (1953). On the basis of their temperature-activity relations this is what might be expected. The brown trout shows a greater scope for activity at higher temperatures than does the speckled trout. The apparent support which these observations provide for the activity hypothesis cannot be pressed in any more serious form. The complexity of the problem may be judged by the diversity of opinions on trout distribution expressed in the literature which King (1943) has summarized most appropriately.

PREFERRED TEMPERATURES

The congregation of fish within a segment of the thermal range available to them has been re-

peatedly observed, both in nature (Dendy, 1945) and in the laboratory (Doudoroff, 1938; Sullivan, 1949; Sullivan and Fisher, 1953). Within the laboratory it is possible to eliminate many of the multiple factors of the natural environment (gradients of light, of gas and chemical content, of food and predator abundance) and to determine a *preferred temperature.* Like the lethal temperature and the temperature for optimum activity, the preferred temperature is subject to change through acclimation. Fry (1947a) has further indicated that a *final preferendum* may be established, where the preferred temperature equals the acclimation temperature.

The recognition of an ability among fish to perceive and select a limited thermal range has found significance in its relation to temperatures for optimum activity. In the goldfish, Fry and Hart (1948) noted that the final preferendum and the optimum temperature for cruising speed corresponded closely. Fisher and Elson (1950), using an electrical stimulus, measured the length of the initial dart made by speckled trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*) parr at various temperatures. The maximum response occurred in the region of the preferred temperature, for the level of temperature acclimation of their samples.

Whatever the mechanism or process of temperature selection may be, the survival value of moving progressively into thermal conditions which offer a maximum expression for activity is most apparent. It is interesting to note that speckled trout are not usually found at temperatures exceeding 19°C., which is the upper limit of their preferred range, although considerably below their upper lethal level.

Doudoroff (1938) concluded from experiments with the marine fish *Girella nigricans* that the temperatures most frequently selected (26–27°C.) were not in keeping with the temperatures of their normal habitat (mean surface temperature of 20.8°C.). This apparent discrepancy may be attributed in part to the phenomenon of summation in acclimation, previously referred to for the bullhead (Brett, 1944, 1946), in which the field collections showed an acclimation to the maximum rather than to the mean temperatures of the environment. From Doudoroff's data, the final preferendum lies between 23° and 24°C., in agreement with the highest mean monthly record of 23.6°C.

DIRECTIVE FACTOR

The laboratory study of preferred temperatures reveals a considerable degree of insensitivity to temperature. The range for a preferred temperature observed among young Pacific salmon frequently amounted to eight Centigrade degrees (Brett, 1952). This would hardly convince the ecologist that temperature could act as a directive factor for the relatively precise migrations of at least one of the species (*Oncorhynchus nerka*). Yet their exodus from lakes has been shown to correlate significantly with rising spring temperatures (Foerster, 1937). Kennedy (1940) discovered a temperature relation between the movement of lake trout from a shallow lake, as it warmed in spring, to a deeper adjoining lake. In Lake Oredon, Jammes (1931) observed that the vertical distribution of trout was related to temperature, their position being apparently defined by that of the 12°C. isotherm. In the ocean, the spring movements of Atlantic mackerel (Sette, 1950) "appear to be spawning migrations in which temperature limits the northerly progress" regardless of feeding conditions.

It is also relevant to note the delicate sense of temperature perception displayed by *Jenkinsia lamprotaenia.* Breder (1951) observed schools of this species to avoid consistently a temperature of 30°C., although moving freely in a temperature of 29.0 to 29.5°C. and capable of withstanding 35°C.

Using the method of conditioned responses, Bull (1936) was able to demonstrate particularly fine temperature discrimination in a wide variety of species. Responses were obtained for temperature increases as small as 0.03 to 0.10°C. A minimum difference of 0.5°C. was required to produce an unconditioned orientation response in two species of *Pomolobus*, the alewife and the glut herring (Collins, 1952).

Critical temperature conditions have been ascribed to maturation and spawning in some fish. Bullough (1939) discovered that in conjunction with long daily periods of artificial light a temperature of 17°C. brought on maturation of the gonads in the minnow *Phoxinus laevis.* A temperature of 17°C. alone was found sufficient to induce completion of spermatogenesis in the stickleback, *Gasterosteus aculeatus* (Courrier, 1922). Craig-Bennett (1930) further noted that in the stickleback a rise in temperature during the spring was sufficient to change "potential maturity" to "functional maturity." Similarly, a rise in temperature

in the presence of vegetation is reported by Fabricius (1950) to release spawning activities in the pike (*Esox*), whereas the whitefish (*Coregonus*) require a lowering of water temperature with a particular character of bottom.

Thus it would seem that an inherent ability to perceive fine gradients of temperature is only exercised when called upon by some internal drive (possibly in some migrations) or by an environmental stress (possibly at higher temperatures). This would constitute a distinction between temperature as a directive factor and temperature as a preferendum. The preferred temperature does not exert such a "pressure" eliciting particular activities, but has a wider range of effectiveness governing the efficiency of performance of the fish.

SUMMARY

Among aquatic gill-respiring vertebrates there is no escape from environmental temperature. Tissue temperature and environmental temperature are constantly equilibrated at the gill surfaces.

Although the thermal requirements for fish have been seen to fall in a number of categories, the fundamental requirement can be restated—an *external* temperature best suited to the *internal* tissues. The tissues themselves are functionally adapted to a wide thermal tolerance, which is bounded by lethal limits and shows great diversity between species.

In general, cold-water fishes have a lower level of thermal tolerance than inhabitants of warmer waters.

Through reversible acclimation, which is more rapid for a rising temperature than for a falling temperature, the degree of tolerance and the activity range is variously extended among species. A slow rate of *decrease* in environmental temperature is of greater importance for maintaining life than a slow rate of *increase*.

The combined information concerning lethal temperature and temperature permitting maximum activity, at all stages of development, is necessary for an interpretation of temperature in terms of survival value. Where high temperature does not limit activity, lethal levels can be expected to be a prominent environmental factor in setting the limits of distribution.

The scope for activity of cold-water fishes finds maximum expression at moderately low temperatures, which appear to be those frequented by the fish as preferred temperatures.

A potential for delicate discrimination of temperature differences among diverse species of fish is probably only exercised under particular environmental conditions.

Temperature, then, may act in the capacity of a lethal factor; it constantly conditions the fish through acclimation while governing the scope for metabolic rate; performance is best in the region of the preferred temperature; and a sensitivity to small gradients of temperature may act as a directive factor. Undoubtedly, the role of temperature among fish is a multiple one.

ACKNOWLEDGMENT

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E X T R A I T

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Cons. Internat. Explor. de la Mer

8.

The Movement of Herring in British Columbia Waters as Determined by Tagging.

With a Description of Tagging and Tag Recovery Methods.

By J. C. Stevenson

Summary.

The tagging and tag recovery programme on British Columbia herring was undertaken primarily to determine the degree of discreteness of herring populations and to delineate the region of inshore concentration of each.

From 1936 to 1951, the number of herring tagged amounted to 555,521 comprising 310 individual taggings. All the fish in each individual tagging were tagged at the same place and at the same time, the object being to have each such tagging consist of fish from a single school.

Taggings were carried out on all main herring stocks in British Columbia waters, but certain stocks were tagged more consistently and more intensively than others. In the early years of the investigation a general coastwise tagging programme was undertaken, but in later years intensive tagging was carried out on the major herring stocks, one after another.

Tagging was undertaken in three main periods of the year: (1) in late winter and early spring after the fishery was over and when the fish were in spawning condition, (2) in the early autumn (in the Strait of Juan de Fuca) at which time fish were moving inshore, and (3) during the period of the fishery. Most of the individual taggings (89 %) took place on spawning or spent fish. Recovery from these taggings was particularly useful in determining extent of intermingling of stocks since at least six months elapsed between tagging and recovery; recovery was not possible until the herring returned to inshore waters from summer offshore feeding grounds and were subjected to the regular autumn and winter fishery.

The tagging procedure involved catching and impounding the herring, making a small incision in the body wall of each fish, and inserting a nickel-plated iron tag through the incision into the body cavity. In the course of the investigation numerous variations in procedure occurred with regard to type of impoundment, length of time the fish were impounded before tagging, method of making the incision, and type of tag used. Differences in recovery arising from these changes in procedure were not statistically significant. It was found, however, that overcrowding of fish in the impoundments prior to tagging led to reduced recovery of the tagged fish.

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Results of experiments suggested that tagging mortality was at least 60 %. These experiments showed that great care was required in handling the fish prior to tagging and in inserting the tags.

Differences were found in tag recovery from taggings carried out by experienced and by inexperienced taggers, but such differences were seldom significant.

Two types of equipment were used in the processing plants to recover tags: electronic tag detectors and magnets. The essential features of detector recovery were an electrically-energized coil placed in a conveyer chute of the plant, which detected the passage of a tag in the chute, and a trap-door system located a few feet further down the chute, which automatically by-passed the tagged fish. The tag detectors were of two types: the bridge type, in which the presence of a tag created an impulse by upsetting the electrical balance of four coils in Wheatstone bridge formation, and the induction type, in which a tag created an impulse by inducing a current in a secondary coil which was connected to a coil with a primary winding. Two models of each type of detector were operated.

The second method of recovering tags involved the installation of electro-magnets and permanent magnets in the meal-line of herring reduction plants. Tags passing over the magnets with the herring meal were held and later picked off the magnets by plant employees. Tags were also obtained from cracks and crevices of plant machinery, and these tags together with those from magnets were referred to as plant recoveries. A reward of 50 cents a tag was paid to plant employees for returning the tags to herring investigators with pertinent information on date and place of capture.

The chief problems in detector recovery were the maintenance of high sensitivity in the field of the detector coil and the proper timing of the opening of the trap-door to ensure recovery of tags detected by the coil. The basic difficulty in maintaining high sensitivity to the presence of tags stemmed from the fact that the impulse created by a tag was never greater (and generally less) than twice the general level of inherent interference within the detection circuit. Outside interference, arising from several sources, sometimes created impulses in the detection circuit which exceeded that produced by tags, resulting in low detector efficiency. Various methods were employed to reduce the effect of outside interference, but they were only partially successful.

Because of the high cost of manufacturing, maintaining, and operating tag detectors, it was possible to install detectors in relatively few processing plants. On the other hand, magnets were installed in all plants at relatively low cost. Over six times as many tags were recovered by magnets and plant machinery as by detectors.

Plant recoveries were less useful in studying herring movements than detector recoveries because some doubt usually existed with regard to the exact fishing locality from which each plant recovery was taken. This uncertainty arose from the fact that a variable period of time elapsed between the unloading of a tagged fish at a plant and the passage of the tag over the magnet. Thus, while knowledge of where a particular load of fish was caught readily identified the area of capture of detector recoveries, this knowledge was frequently insufficient to give positive identification of the locality of capture of tags taken from magnets or plant machinery. The extent of the time lag in various plants was investigated, and this information was sometimes helpful in interpreting the area of recovery of plant returns. The efficiency of plants in recovering tags from the catches was generally greater than the efficiency of detectors.

The general method of studying the intermingling of herring stocks necessitated relating the actual numbers of tag recoveries to the estimated total number of tags in the catches. Certain assumptions were involved in this method of analysis. They pertained to rate of exploitation, recruitment, intensity of tagging, and random distribution of tagged fish in the stocks.

The total number of tags recovered in the fishing seasons from 1936—37 to 1951—52 was 20,328, or 3.7 % of the number of fish tagged. The percentage recovery was considerably greater in the later years of the study than in the early years, due mainly to increased opportunity for plant recovery and generally increased exploitation of the herring stocks. All but 14 of the 310 individual taggings produced returns. Recovery of tags decreased with increase in time between tagging and recovery.

The recovery data revealed a strong tendency for tags to be recovered in or near the area of tagging, indicating that most herring return in the autumn and winter to the inshore area in which they spawned the previous spring. It was concluded that British Columbia herring comprise a limited number of more or less distinct populations, a conclusion which is in general agreement with results from studies on meristic characters, age composition, and growth.

Migratory and resident herring populations were distinguished on the basis of population abundance,

seasonal migration, growth and age composition, location of spawning grounds, and homogeneity of individual runs. Eight migratory populations were identified according to the general coastal regions in which they spawn and are fished: (1) the east coast of the Queen Charlotte Islands, (2) northern mainland coast, (3) north central mainland coast, (4) south central mainland coast, (5) middle east coast of Vancouver Island, (6) lower east coast of Vancouver Island, (7) south-west coast of Vancouver Island, and (8) north-west coast of Vancouver Island. There is a tendency for the main fishing and spawning grounds of each population to be located in the more southerly part of the region (or sub-district) of their inshore concentration, and for movement within each sub-district to be northerly. This has suggested that the route of migration from offshore feeding grounds to inshore waters is also northerly, and this indication is supported by the only tag recovery taken from offshore waters. The migratory populations provide about 95 % of the annual herring catch.

The numerous small resident populations are mostly concentrated in the long inlets of the north central, south central and upper east coast regions. Information on their movements is sparse since not all have been tagged. They show a considerable degree of isolation from neighbouring migratory populations and from each other. Herring of resident populations are relatively slow-growing, suggesting that their summer feeding areas are less productive than the offshore feeding areas of the migratory stocks.

The recovery data indicated that about one-quarter of the fish of each major migratory population emigrates to other populations. Fish of the middle east coast of Vancouver Island showed the greatest emigration (45 %), an indication that this population was the least independent stock. Least emigration occurred from the lower east coast population (16 %).

The amount of emigration from one population to another varied with the distance separating the populations. It was concluded that the herring of British Columbia tend to form a series of intergrading populations.

The individual herring runs of the south-west coast and north-west coast of Vancouver Island showed a type of intergradation which resembled, on a smaller scale, the intergradation of the major migratory populations. There was evidence that the individual runs within the northern and north central populations also followed this pattern. In contrast, the runs within the population of the lower east coast of Vancouver Island appeared to be freely mixing and homogeneous showing no differential emigration outside the sub-district.

Emigration from individual herring runs of the middle east coast resembled that of the runs of the west coast populations in certain respects. However, the presence within this sub-district of resident or partially resident stocks, as well as a migratory stock, resulted in a relatively complicated situation.

BIANCO LUNO A/S. KBH

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Epidiopatra hupferiana Augener from the North-East Pacific

THE little-known polychaete genus *Epidiopatra*, belonging to the family Eunicidae, was set up by Augener[1] in 1918 to contain two species, *E. hupferiana* and *E. drewinensis*, both collected off the west coast of Africa. No other species has since been added to the genus. The only subsequent record of either species is that of *E. hupferiana* from South Africa by Monro[2] in 1930. Both Augener's and Monro's specimens were dredged on muddy or sandy bottoms and, in Augener's case, mention is made of their inhabiting tubes.

Capture of a specimen of *E. hupferiana* in a plankton tow, from 100 ft. to surface, in Hecate Strait, British Columbia, seems worthy of record. It was taken by Mr. R. J. LeBrasseur, of this Station, in June 1955. The specimen is small (about 12 mm. long); but the characters are unmistakable. The generic characters are essentially those of the better-known Eunicid genus *Diopatra*, except that tentacular cirri are entirely absent and there is a very limited number of branchiferous segments. In all technical details the specimen agrees completely with Augener's and Monro's descriptions of *E. hupferiana*.

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[1] Augener, H., "Beiträge zur Kenntnis des Meeresfaunas West-Afrikas" 2, Pt. 2, 355 (1918).
[2] Monro, C. C. A., Discovery Reports, 2, 125 (1930).

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THE NORTHERN LIMITS OF DISTRIBUTION IN MANITOBA FOR CYPRINID FISHES[1]

By J. J. Keleher

Abstract

Twenty-three species of minnows (Cyprinidae) are known to occur in the Province of Manitoba, Canada. The most northern collection of each in the province has been listed and mapped. In Manitoba 13 minnows reach the northern limit of their recorded distribution. The limit of some species appears to be related to the 65° July isotherm.

Introduction

Published information on the northern boundary of the distribution of the freshwater fishes of Canada is not very extensive. The most northerly collection records in the Province of Manitoba are presented for the minnows. The purposes of this paper are to supplement our present knowledge and to provide a standard for future work.

Materials and Discussion

The writer's records are based on approximately one hundred collections. The fish were secured by seining in those areas accessible by roads. A transcription of the Manitoba fish records in the Royal Ontario Museum has been examined. Although the specimens have not been seen, these records have been utilized and have extended the limits of nine species. The limits for any species cannot be regarded as final because fish collections have not been made in many areas of the province. The nomenclature used by Dymond (1) has been followed.

Table I lists the most northern collection record in the province for 23 minnows. An exception is *Notropis cornutus*. Kendall's record (5) is farther north than the Woody River but this alternative has been provided since the former is geographically indefinite. The following records have been published previously: *Hybopsis storerianus* (2), *Notemigonus crysoleucas* (4), and *Notropis blennius* (1). *Nocomis biguttatus*, *Rhinichthys atratulus*, and *Notropis rubellus* are recorded for the first time in Manitoba. In each case their presence was suspected by Hinks (3) because of occurrence in adjacent regions.

A figure has been presented to facilitate locating the places listed in Table I. Species which have a more northern record outside Manitoba are shown by open circles. Locations which are the most northern limit of the species, regardless of region, are shown by closed circles. Thirteen species have the most northern limit of their entire published distribution in Manitoba: *Cyprinus carpio*, *Semotilus atromaculatus*, *Margariscus margarita*, *Nocomis biguttatus*, *Hybopsis storerianus*, *Rhinichthys atratulus*, *Notemigonus crysoleucas*, *Notropis rubellus*, *Notropis cornutus*, *Notropis blennius*, *Notropis deliciosus*, *Hybognathus hankinsoni*, and *Hyborhynchus notatus*.

[1]*Manuscript received May 7, 1956.*
Contribution from the Fisheries Research Board of Canada, Biological Station, Winnipeg, Man.

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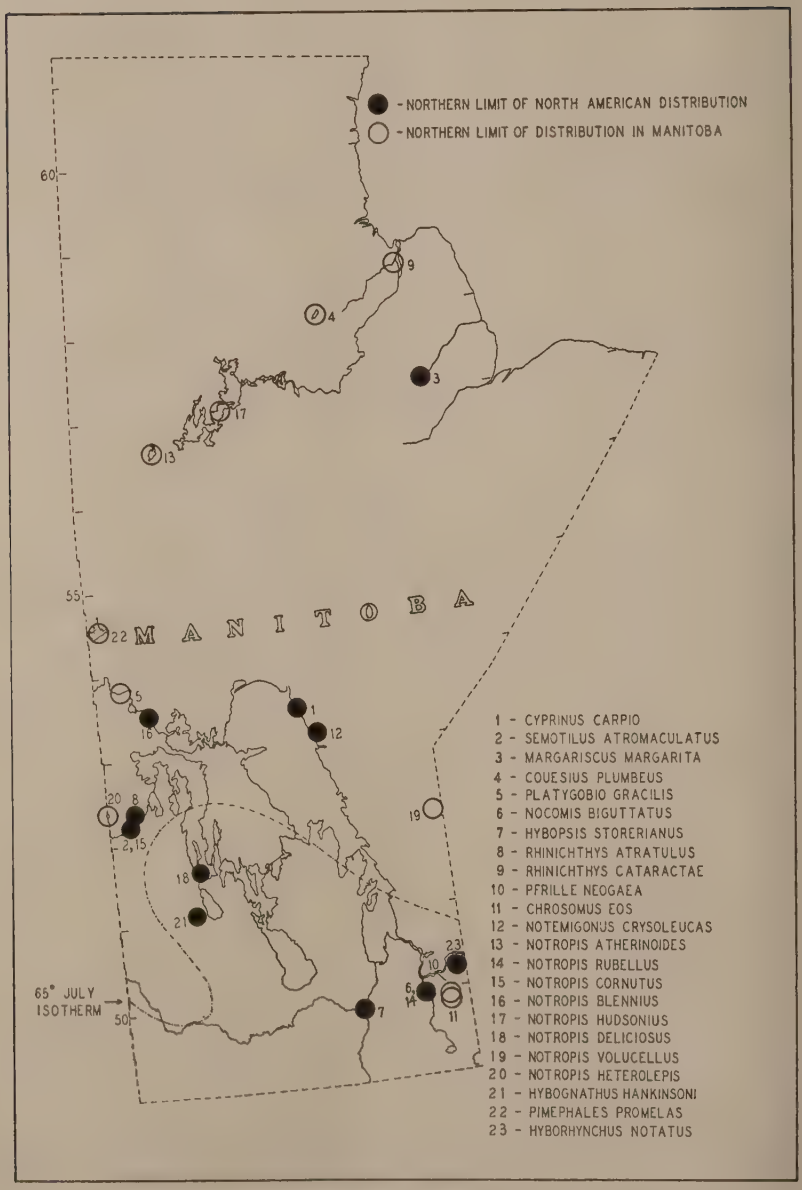

FIG. 1. The most northern record of occurrence in Manitoba for cyprinid fishes.

TABLE I

THE MOST NORTHERN RECORD OF OCCURRENCE IN MANITOBA

Species	Location	N. Lat.	W. Long.	Collector	Year
Cyprinus carpio	Spider Island	53° 29′	97° 45′	B. Kooyman	1954
Semotilus atromaculatus	Woody River	52 13	101 15	J. J. Keleher	1955
Margariscus margarita	Silcox Creek*	57 09	94 10	B. Kooyman	1951
Couesius plumbeus	South Knife Lake*	58 10	96 28	K. C. Dey	1950
Platygobio gracilis	Saskatchewan River	53 50	101 15	W. M. Sprules	1947
Nocomis biguttatus	Whitemouth River	49 57	95 59	J. J. Keleher	1954
Hybopsis storerianus	Red River	49 53	97 09	C. H. Eigenmann	1892
Rhinichthys atratulus	Birch River	52 23	101 06	J. J. Keleher	1955
Rhinichthys cataractae	Trib. of Herriot Creek*	58 33	94 22	B. Kooyman	1951
Pfrille neogaea	Brereton Lake*	49 54	95 34	J. A. McLeod	1944
Chrosomus eos	Rennie Creek	49 50	95 40	J. J. Keleher	1955
Notemigonus crysoleucas	Mukutawa River	53 09	97 25	J. J. Keleher	1947
Notropis atherinoides	Eden Lake*	56 38	100 15	B. Kooyman	1948
Notropis rubellus	Whitemouth River	49 57	95 59	J. J. Keleher	1955
Notropis cornutus	Woody River	52 13	101 15	J. J. Keleher	1955
Notropis blennius	Baptizing Creek	53 32	100 42	V. E. F. Solman	1941
Notropis hudsonius	Southern Indian Lake*	57 05	98 34	B. Kooyman	1948
Notropis deliciosus	Mossy River*	51 39	99 56	G. E. Butler	1943
Notropis volucellus	Fishing Lake*	52 07	95 24	G. E. Butler	1946
Notropis heterolepis	Pickerel Lake	52 27	101 39	R. K. Stewart-Hay	1952
Hybognathus hankinsoni	Vermillion River	51 09	100 03	J. J. Keleher	1954
Pimephales promelas	Lake Athapapuskow*	54 33	101 40	J. A. McLeod	1944
Hyborhynchus notatus	Echo Lake*	50 13	95 22	T. A. Paddock	1949

**Records from the Royal Ontario Museum fish collection.*

The distribution of the minnows may be viewed in relation to isotherms. Radforth (6) suggested that the following species had a distributional trend in Ontario apparently related to the 65° (F.) July isotherm: *Semotilus atromaculatus*, *Margariscus margarita*, *Rhinichthys atratulus*, *Chrosomus eos*, *Notemigonus crysoleucas*, *Notropis rubellus*, *Notropis cornutus frontalis*, *Notropis deliciosus*, and *Hyborhynchus notatus*. The 65° isotherm as given by Thomas (7) has been plotted on the figure. All but one of these have their northern limit of known distribution in Manitoba between the 64° and 66° isotherms, although *Notemigonus crysoleucas* is only barely on the 64° line. *Margariscus margarita*, however, occurs farther north a little north of the 60° isotherm.

Acknowledgments

I am indebted to W. B. Scott, who has permitted the transcription of the Manitoba fish records in the Royal Ontario Museum and the publication of nine records from this list. He has verified some of my identifications. Assistance has been received from B. Kooyman, K. F. Lagler, and G. H. Lawler. Acknowledgment is made to those collectors who have contributed unpublished records. Miss Catherine L. Beniuk prepared the figure.

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The Kinetics of the Hydrogenation of Pure Fatty Esters.
I. Mono-Olefinic Systems: Methyl Oleate

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A RECENT PAPER by Swicklik *et al.* (11) has presented, along with their own interesting contribution, a survey of the literature concerning the kinetics of fatty oil hydrogenation. The considerable confusion which existed in this field of research prior to 1941 was complicated, as they pointed out, by unsatisfactory data. As evidenced by the more recent publications on the subject, this state of affairs is being corrected gradually by studying the hydrogenation of simple, pure unsaturated compounds, carried out under well-controlled conditions, thus allowing the basic features of the problem to emerge. A further step would be to make use of the fact that the reactions involved are taking place on the surface of a catalyst and, as such, are governed by the laws of adsorption. These should be involved in any attempt at setting up rate equations.

The present series describes work accomplished with simple alkyl esters under conditions designed to suppress complicating side reactions and to permit accurate measurement of the rate of hydrogen absorption. Absorption rate data obtained in this way reflect the simple kinetics involved in the reaction.

The present article discusses data obtained on hydrogenating methyl oleate. Their implications are basic in interpreting the more complicated systems described in the following articles of this series.

Experimental

REAGENTS

Methyl oleate was obtained from olive oil through methanolysis, fractional molecular distillation of the crude esters, several fractional crystallizations from acetone, and a final fractional distillation, using the Podbielniak semi-automatic microanalyzer. The product showed the following analysis:

hydrogen value, 0.680 (13); required, 0.680.
refractive index at 20°C., 1.4515; reported, 1.4515 (7).

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Spectrophotometric analyses (before and after alkali-isomerization) detected no conjugated or polyunsaturated impurities.

Stored under nitrogen in sealed ampoules kept in the refrigerator, the ester was transferred to hypodermic syringes for weighing according to a technique already described (14).

Ethyl alcohol was obtained by refluxing under nitrogen 95% fermentation alcohol over caustic soda for several hours and fractionally distilling the product under nitrogen. The water content was 5%; transmittance against distilled water was 60% at 220 mμ.

Dibutyl-ether was obtained by careful fractional distillation over sodium of Eastman Kodak (white label) product. Found: B.P. 142.5°C. under 760 mm.; reported, 142.4°C. (12).

Catalysts

The *Raney nickel* catalysts were different preparations of the W-5 type (5) obtained and kept as suspensions in ethyl alcohol. All were stored in the refrigerator between uses, some under hydrogen, others without this extra precaution. Pipetting from these well-stirred suspensions provided approximate amounts of catalyst. An accurate determination of the nickel involved in each experiment was made after it was completed.

The *platinum catalyst, PS 14,* was described in a previous paper (15).

Apparatus and Technique

The hydrogenations were conducted at 25.0°C., under 760 mm. Hg., in ethyl alcohol or dibutyl ether, using an apparatus and a technique already described (14). Readings of the buret were taken every minute, and the rate of absorption at minute i was taken as

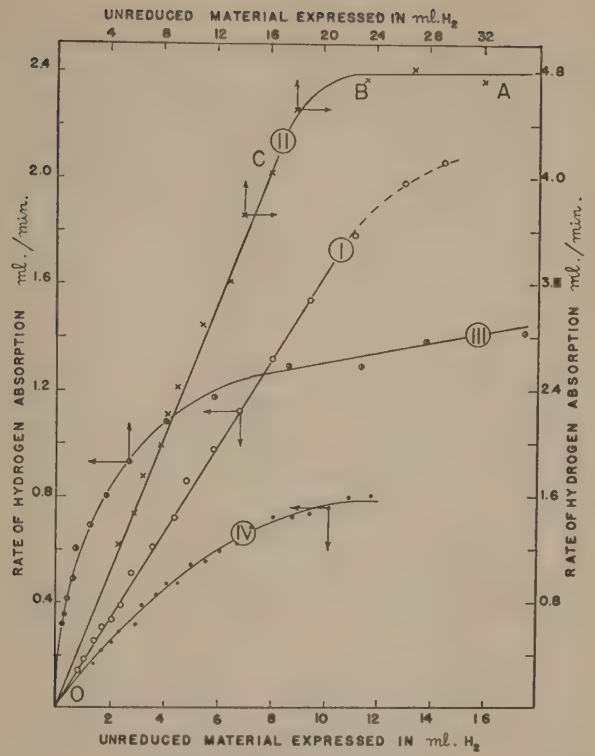

FIG. 1. Hydrogenation Rate Curves.

Curve I: Methyl oleate in 95% ethyl alcohol with Raney nickel showing first order relationship.

Curve II: Same system as for Curve I but with larger amounts of both methyl oleate and Raney nickel resulting in zero order kinetics (AB) during the early stages.

Curve III: Methyl oleate in 95% ethyl alcohol with a platinum catalyst.

Curve IV: Methyl oleate in dibutyl ether with a platinum catalyst.

Related coordinates for the various curves are indicated by the arrows.

half the volume change observed between minute $i-1$ and $i+1$. Hydrogen absorption rates were then plotted against the volume of hydrogen still to be absorbed. Obviously this volume is proportional to the concentration of double bonds present in the medium.

Results

When methyl oleate was hydrogenated in the presence of Raney nickel W-5, the absorption curves closely approximated a straight line as shown by curve I, Figure 1; deviations were small (Table I)

TABLE I

Hydrogenation Rate of Methyl Oleate with Raney Nickel
(Me oleate W5 – 1. Run 9–266. $H_o = 16.80$)

T Time	H, Concn.	1n H_o/H	k = 1/T 1n H_o/H
4	10.66	0.455	0.1137
5	9.49	0.571	0.1142
6	8.45	0.687	0.1145
7	7.49	0.808	0.1154
8	6.65	0.926	0.1158
9	5.93	1.041	0.1157
10	5.25	1.163	0.1163
11	4.66	1.282	0.1166
12	4.15	1.398	0.1165
13	3.71	1.510	0.1162
14	3.34	1.610	0.1150
18	2.15	2.056	0.1142
22	1.34	2.528	0.1148
24	1.04	2.782	0.1159

except for the initial points which showed the effect of a lag resulting from delayed solution of the sample when dropped into the alcohol-catalyst suspension. A linear relationship was found regardless of wide variations in the age, effectiveness, and method of storage of the catalyst as well as in the catalyst-methyl oleate ratio. The only limitation was imposed by the necessity of working at absorption rates no greater than 4.5 ml. of hydrogen per minute; somewhat beyond this limit distortion of the rate curves would occur (Figure 1, curve II). Assuming an initial horizontal course AB (constant rate), they would curve down gradually until, when the 4.5 ml. per minute limit was attained, a straight line OC was formed. If all other conditions are equal, the length of the initial plateau would be greater at lower agitation rates; however once the straight, oblique branch had been reached, increasing the agitation could not induce a change of course. This showed conclusively that saturation of the medium with hydrogen had occurred. Consequently data typified by curve I, Figure 1, are comparable in having been obtained under conditions identical with respect to the hydrogen supply. This effect of agitation has also been reported elsewhere (9).

Curve III, Figure 1, shows the completely different type of curve obtained when, if all other conditions are equal, platinum catalyst PS 14 was substituted for Raney nickel W-5.

When the same platinum catalyst was used and alcohol was replaced by dibutyl ether, curves exemplified by curve IV, Figure 1, were obtained. Under the same conditions the family of curves shown in Figure 2 was obtained when methyl stearate was added to the medium. A progressive decrease in hydrogenation rate was observed when the amount of methyl stearate was increased.

No significant decrease could be detected when methyl stearate was added to methyl oleate-alcohol-Raney nickel W-5 systems.

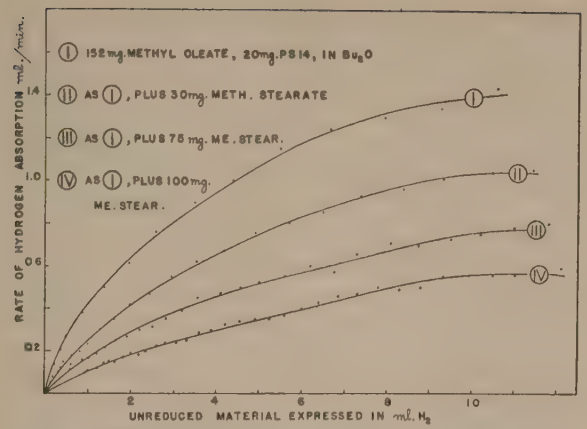

FIG. 2. Family of hydrogenation rate curves obtained with methyl oleate, a platinum catalyst, in dibutyl ether with increasing amounts of methyl stearate.

Discussion

The results show that the kinetics of the oleate-alcohol-Raney nickel system are adequately described by

$$\text{methyl oleate} \xrightarrow{k_0} \text{methyl stearate}$$

$$\text{Hydrogen absorption rate} = dH/dt = -k_0 H \quad (1)$$

where k_0 is a constant equal to the slope of the absorption rate line, and H the volume of hydrogen still to be absorbed to complete the reaction. In this reaction the hydrogen absorbed corresponds mole for mole to the ester hydrogenated; thus:

$$dA/dt = -k_0 A \quad (2)$$

where A is the concentration of methyl oleate.

In writing expression 2, it is assumed that no *trans* or *iso* oleate is formed during the reaction. This is reasonable in view of the results of Feuge *et al.* (4) and of those of Swicklik *et al.*, showing a considerable decrease in isomerization as the temperature decreases.

Bailey (1) has made, concerning the rate of hydrogenation of double bonds, an assumption leading to an apparently similar expression. However he made it quite clear that only relative rates were considered while expression 2 involves the absolute rate. A first order relationship between the rate and the concentration of the reactant is remarkable, although not unique, for heterogeneous reactions involving adsorption. The rate is dependent on catalyst densities of coverage, and these are usually complex functions of reactant concentrations. As shown by curve III, Figure 1, a more complex relationship is found when a platinum catalyst is used. Expression 2, which appears to be the rule with nickel catalysts, is highly suggestive of a mechanism similar to that proposed by

Rideal (8) and applied by Rideal and Eley (3) to the interpretation of para-ortho hydrogenation conversion. This mechanism differs from the classical Langmuir-Hinshelwood concept of heterogeneous catalytic reactions in that it necessitates the adsorption of one of the reactants only. The impact of molecules of the other reactant with activated molecules of the adsorbed reactant would bring about the reaction. If methyl oleate reacted as a result of impacts against activated hydrogen molecules or atoms covering the catalyst, the over-all rate of reaction would indeed be proportional to the concentration of methyl oleate in the medium since the number of impacts would be proportional to this concentration.

However Laidler (6) considers the classical mechanism as the more frequent and also the more probable since it would involve lower energies of activation; the reactants both are adsorbed. Furthermore he concludes that one characteristic of the Rideal type of mechanism would be a strong adsorption of the product of reaction. Our results have shown that this is definitely not the case since addition of methyl stearate does not alter the rate of reaction. It is the case with a platinum catalyst however (Figure 2).

The more probable mechanism is thus the classical one which assumes that the reaction takes place between adsorption complexes of the reactant.

In establishing rate equations for heterogeneous catalytic reactions, the concept of "reactant coverage" is used instead of the "reactant concentration" concept applied in homogeneous systems. The same reaction rate expressions can be used, providing such substitution be made. In the case at hand the reaction would be considered "bimolecular," *i.e.*, the rate is proportional to the mole fraction ϕ of methyl oleate and the mole fraction ψ of hydrogen adsorbed per unit area. Let D be the total area and F a "velocity constant," then

$$da/dt = -FD\phi\psi \qquad (3)$$

would express the over-all rate of reaction. Terms ϕ and ψ are complex functions of the variables, *i.e.*, the concentrations of all solutes engaged in adsorptive competition. The results have shown that methyl stearate, one of the solutes, is not involved.

Before attempting to formulate ϕ and ψ, the adsorption model for both hydrogen and oleate has to be defined. For the strongly chemisorbed hydrogen there is little doubt that the adsorption is of the monolayer type. A multilayer model for methyl oleate is excluded since the observed linear relationship between rate and concentration is incompatible with the existence of a gradient in energy of activation. This would be manifest at some point of the concentration range if multilayer coverage were replaced by a monolayer one. The type of curve obtained with a platinum

catalyst, on the other hand (Figure 1, curve III), is reminiscent of the B. E. T. isotherms and strongly suggestive of a multilayer model.

There is thus every suggestion that the simple Langmuir theory of adsorption applies in the case of a nickel catalyst. Hence one can write the classical expressions of catalyst density of coverage, assuming ϕ and ψ to be proportional to these densities; G and J are the appropriate proportionality constants:

$$\phi = GMA/(1 + MA + RH)$$
$$\psi = JRH/(1 + MA + RH) \qquad (4)$$

In the above expressions M and A are, respectively, the adsorption constant and the concentration of methyl oleate in the medium; R and H represent the corresponding quantities for hydrogen. Substituting these values for ϕ and ψ in expression 3:

$$dA/dt = -GJFDMARH/(1 + MA + RH)^2 \qquad (5)$$

H is a constant corresponding to the saturation concentration of hydrogen. The expression will describe the experimental results when term MA in the denominator is negligible since it then can be written in the following form, identical to expression 2:

$$dA/dt = -k_oA$$

with

$$k_o = GJFDMRH/(1 + RH)^2 \qquad (6)$$

all terms in expression 6 being constants.

Since term MA is negligible when M is very small, one must conclude that methyl oleate is very weakly adsorbed.

Zero Order Kinetics

Zero order kinetics, such as indicated by branch AB, curve II in Figure 1, occur when the rate of hydrogen diffusion is constant and lower than the rate of the reaction with a hydrogen-saturated medium. Conditions for the establishment of this type of kinetics can be found by assuming any change in the factors in equation 5 which will tend to increase the rate of reaction. Zero order kinetics are thus likely to occur:

a) when F is large, *i.e.*, when the catalyst is very effective or when the temperature is high;

b) when D is large, *i.e.*, when the amount of catalyst or its effective area for unit weight is large; and

c) when A is large, *i.e.*, when the concentration of unsaturated compound is high.

The same result would be obtained by decreasing the rate of diffusion by one of the following means: reducing the gas-liquid interface; lowering the pressure; increasing the temperature to reduce hydrogen solubility; reducing the rate of admission.

It is evident from c) that a change from zero order to a higher order of kinetics must occur in the course of any batch hydrogenation experiment whenever

zero order conditions existed at the start (Figure 1, curve II).

The above rules apply to hydrogenations carried out under industrial conditions. In the recent article by Swicklik *et al.* (11) their Figure 3 shows the rate of tristearate formation at 175°C., under 1 atmosphere, to be a linear function of time. At the same temperature, but under 65 lb. of pressure (Figure 4), this rate is proportional to time only until about 50% stearate has formed; from then on, the plot indicates kinetics of a higher order. Under 1 atmosphere but at a lower temperature (125°C., Figure 2), the rate of hydrogenation is of a higher order throughout. See also the data of Feuge *et al.* (4) containing many examples of over-all zero order kinetics.

A very important point must be made in relation to all these cases. Because of the slow, constant rate of diffusion of the hydrogen, the hydrogen coverage of the catalyst is very small and constant. But the Langmuir equilibrium is maintained in the case of the unsaturated compounds. In the case of methyl oleate equation 4 assumes, under zero order conditions, the simple form:

$$\phi = \mathrm{GMA} \qquad (7)$$

since H has now become very small and term RH is negligible. Variation of A in the course of the reaction does not influence the rate simply because ϕ is so much larger than the constant hydrogen coverage. The case is analogous to that of a bimolecular homogeneous reaction where concentration of one reactant is much higher than the concentration of the other one and when, by some device, the latter is kept constant.

If several unsaturated species are present in the system, a relation such as 7 would apply to their respective coverages, and the small, constant hydrogen coverage available would be competitively shared by all adsorbed reactants proportionally to both their respective coverages and reactivities. This principle was postulated in a somewhat different form by Bailey and Fisher (2). Its successful application in interpreting the kinetics of the more complex systems constitutes the subject of the next article of the present series.

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Partition Chromatography of Aliphatic Acids

Quantitative Resolution of Normal Chain Even Acids from C_{12} to C_{24}

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Partition Chromatography of Aliphatic Acids

Quantitative Resolution of Normal Chain Even Acids from C_{12} to C_{24}

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Reversed-phase chromatography on a silane-treated silicic acid column, with 2,2,4-trimethylpentane (isooctane) as stationary phase and aqueous methanol as eluting solvent, allows the quantitative resolution of mixtures of even-numbered, normal-chain saturated fatty acids in the range C_{12} to C_{24}. Less than 50 mg. of mixed acids are needed. The elution and titration of the seven acids require about 5 hours. Individual components representing 10% or more of the mixture are determined with an error not exceeding 2.5%. An almost comparable degree of accuracy is attainable for minor components (1 to 3% of the total mixture), when a procedure involving a complementary analysis is followed. A device for automatically and continuously changing the composition of the eluting solvent and a semiautomatic, motor-driven microburet are described. The method is applicable to the determination of the relative proportion of each carbon series represented in a fat sample and the relative proportion of saturated to unsaturated acids in each carbon series.

IN 1951 the present authors undertook to devise a quantitative chromatographic method for the estimation of even saturated fatty acids from C_{12} to C_{24} which could be used to analyze fats of marine origin. It was known that two mixtures of saturated acids could be obtained from such fats, the first resulting from complete hydrogenation of the sample and the second, from removal of all unsaturated components through oxidative degradation. Each of these mixtures would be chromatographed and the results combined to yield the respective proportions of saturated and unsaturated acids within each carbon series. Although no detailed information concerning individual unsaturated components would be obtained, a true picture of the fat structure would emerge.

One proposed application of such a procedure was the study of changes occurring in the fatty acid composition of fat in fishes and marine mammals during their life cycles. As this would require routine analysis of many samples, detection of relatively small changes, and estimation of small amounts of certain acids, a highly standardized and accurate method was needed.

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Only the methods of Howard and Martin (*8*) and of Boldingh (*3*) were known at the time this investigation was undertaken. Mealorub powder could not be secured to try the method of Boldingh; the other method was found unsatisfactory over the range C_{12} to C_{24}. Successive modifications of the latter have led to the method described herein.

Others have described separations of even saturated acids of high molecular weight (*9, 10, 14*). These procedures covered sections of the range C_{12} to C_{24}; the recoveries were not fully quantitative.

Applications of the method of Howard and Martin involving combination of two complementary chromatograms (*4, 5, 11, 12, 15*) all had one point of similarity with the proposed method: One of the chromatograms used was that of a mixture of saturated acids derived from the original mixture, either by complete hydrogenation (*11, 15*) or by elimination of unsaturated components through oxidative degradation (*4, 12*). However, they all used the intact original mixture of acids for the complementary chromatogram to secure detailed information on all acid components. Moderately quantitative results were obtained with simple fats (*4, 5, 12*) or with simple fractions from fats (*11, 15*). Silk and Hahn showed that the chromatographic method used is semiquantitative only (*14*) in estimating the even saturated acids from C_{16} to C_{24}. It is believed that these applications could be improved by the use of the more accurate method described below. In separating the unsaturated acids from the original mixture, the method of Schuette and Dal Nogare (*13*) is used to eliminate acid oxidation products completely, thereby avoiding possible interference in the chromatogram of the saturated components.

OUTLINE OF METHOD

The present method has one basic feature in common with that of Howard and Martin (*8*) for the separation of acids from C_{12} to C_{18}. The column material is treated with dichlorodimethylsilane to render it unwettable by polar solvents. It has much in common with a method proposed by Vandenheuvel and Hayes (*16*) for the analysis of the monocarboxylic acids from C_2 to C_{12}: the type of Trubore glass column used; the commercial grade silicic acid used to prepare the column mixture; the procedure for mixing and packing the column material using the same packing tools; the procedure for loading the column; and the method for detecting band boundaries. The latter, which consists in timing the neutralization by acid eluate of successive alkali increments, requires the maintenance of a constant rate of elution; this is achieved by using a constant hydrostatic head of solvent instead of the constant pressure used in the method for the lower acids.

There are other differences from the Vandenheuvel and Hayes method: Only one packing is used to cover the entire range of acids; the unknown acid mixture is loaded on the column as a chloroform solution; the silicic acid is silane-treated; and the phases are reversed, 2,2,4-trimethylpentane being the stationary phase and aqueous methanol the eluting solvent. A simple arrangement ensures the continuous and automatic change from an initial 75% methanol to practically 100% methanol towards the end of the analysis. The receiver used for the continuous collection and titration of eluate is fitted with electrodes connected to a pH meter. This modification was rendered possible by the

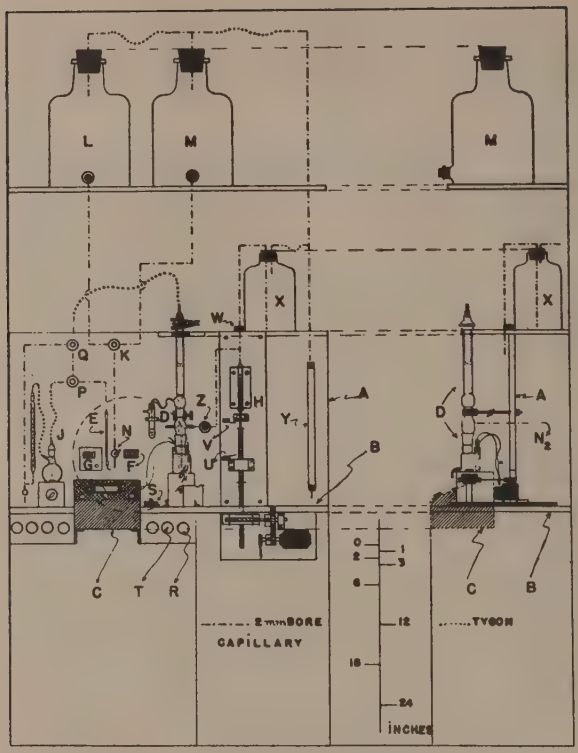

Figure 1. General layout of equipment

A. Wood panel
B. Table
C. pH meter (Beckman Model H-2)
D. Column assembly
E. Flow meter (Emil Greiner No. G-9142 Flowmeter)
F. Counter, Type U. S. Magnetic, lever reset, 110-volt a.c. (Veeder-Root, Hartford, Conn.)
G. Chronometer (Lab-Chron, Laboratory Industries, Inc., Chicago, Ill.)
H. Piston buret, motor-driven
J. Solvent mixer
K. Stopcock, straight-bore, three-way
L. Reservoir for methanol A, 20-liter
M. Reservoir for methanol B, 20-liter
N. Needle valve (Fisher packless)
P. Stopcock, straight-bore, three-way
Q. Stopcock, straight-bore, three-way
R. Selector switch
T. Switch
S, U, V. Microswitches
W. Microvalve size 0–1 and special rectifier (International Instrument Co., Los Angeles, Calif.)
X. Reservoir for alkali, 2-liter, brown glass
Y. Tube, contains soda lime and indicating carbon dioxide absorbent
Z. Stopcock, Teflon-plugged, two-way capillary

polar nature of the effluent; it is of great assistance in detecting band boundaries by the method of successive titrations in permitting easy and accurate determination of end points. For the last modification a semiautomatic, motor-driven piston microburet is used instead of the common type.

An analysis involving seven acids requires about 50 mg. of test material and takes less than 5 hours. Major components ($\geq$ 10% by weight of the mixture) are determined with an error smaller than 2.5% by a single analysis. Under the same conditions, the error on minor components (1 to 3% of the mixture)

may attain 20%. However, the performance of a complementary analysis reduces this error to an estimated 5% and decreases the error on major components in about the same proportion.

APPARATUS

General Layout. Most of the apparatus (Figure 1) is permanently fastened to wood panel *A* or table *B*. Sitting in front of panel *A*, the operator has all the controls within easy reach; under his direct vision are the only parts which require his attention: pH meter *C*, column assembly *D*, flow meter *E*, counter *F*, and chronometer *G*. Motor-driven piston buret *H* and solvent mixer *J* require no attention.

The position of stopcock *K* determines whether solvent will flow to the column from *L* (methanol A) or from *M* (methanol B). The rate of flow is adjusted by the opening of valve *N* with the help of flow meter *E*. On changing the position of stopcocks *P* and *Q* solvent will flow to the column either directly or through solvent mixer *J*.

Operation of the buret piston is commanded by switches *R*, *S*, and *T*. The position of selector switch *R* determines whether the piston is to move upward (delivery) or downward (filling). Pressing microswitch *S* energizes the drive motor, inducing movement of the piston only for the duration of the contact. Switch *T*, by shorting the leads to switch *S*, allows sustained, unattended filling or delivery; microswitches *U* and *V* interrupt the motor when the buret is filled or empty. When selector switch *R* is on "fill," valve *W* opens, admitting alkali from reservoir *X* to the buret. The amount of alkali delivered by the buret is registered by counter *F*.

Reservoirs *L*, *M*, and *X* are connected to tube *Y*, containing soda lime and indicating carbon dioxide absorbent. Stopcock *Z* on the alkali delivery line from the buret is turned off when the latter is being refilled.

Column Assembly. Figure 1 shows column assembly *D* set up for a run. Figure 2 shows the various borosilicate glass parts of this assembly. During a run, column I is fitted with adapters II and III. The latter is connected to the column by clamping securely the two parts of the common ball joint. The column itself fits on the 24/40 standard taper joint of adapter IV, while receiver V is connected to the latter through a 39/45 standard taper joint.

Solvent is led to the column through adapter III which is connected to the solvent dispensing system by small-section Tygon tubing. The effluent from the column reaches the receiver through adapter II, which passes through adapter IV. This arrangement leads the eluate directly to the receiver, avoiding splashing and evaporation and thus preventing the higher acids from crystallizing out before reaching the receiver.

The body *A* of the column proper (Figure 2), has a coarse fritted-glass disk, *B*, sealed at the bottom, followed by outlet tube *C*, and ended by tip *D*. Vent *E* prevents tube *C* from filling up. A small piece of rod, *F*, is sealed on the inside of *C*, its extremity touching the center of disk *B*; this prevents drops of eluate from stagnating under *B*. *G* provides an outlet for the nitrogen bubbled through the receiver; it is fitted with a length of small section rubber tubing leading the nitrogen to a water-filled bubble counter (Figure 1).

Adapter II is fitted to the column by inserting *D* through the hole in Teflon plug *H*. Vent *I* prevents the adapter from filling itself with liquid.

When adapter III is clamped in position, tip *K* is located 3 to 5 mm. above the silicic acid column. Inlet tube *L* is ring-sealed to the bottom of *J*. Cork *M* ensures the rigidity of *L*, thus protecting the ring seal in tip *K*.

Adapter IV (Figure 1) is clamped to vertical board *A*. This adapter supports the column and provides a permanent connection for the column assembly with both the nitrogen supply (Figure 2) through inlet *N* and with the alkali supplied by the buret through inlet *O*. Delivery tip *P* is removable for eventual cleaning.

Receiver V is a four-necked, flat-bottomed flask. Neck *Q*

allows the flask to be slipped on and off adapter IV, the normal position being as shown. Neck *R* is fitted with a calomel electrode and neck *S* with a glass electrode, both connected to the pH meter by 30-inch leads. The meter is carefully grounded and supplied with stabilized current (constant voltage transformer, 0.26 ampere, Sola No. 30804). The electrodes are fitted on necks *R* and *S* with the help of rubber sleeves, ensuring an air-tight seal yet allowing their easy removal; their lower ends are located about 10 mm. from the bottom of the flask.

Neck *T*, which is normally corked, allows the introduction of reagents in the course of a run.

Elastic band *U* maintains scale *V* in a position established by gaging the flask fitted with the electrodes and in operative position. The zero of this scale corresponds to a permanent mark, *W*, made on the flask after determining the lowest level of liquid which will ensure sufficient immersion of the electrodes when the stirrer is in operation.

Outlet *X* is connected to delivery tip *Y* by a piece of rubber tubing; pinch clamp *Z* allows liquid to be withdrawn.

The stirrer (Figure 1) is a 20-mm. length of 6-mm. diameter, Teflon-covered Alnico magnet rod. The entraining magnet is a 42-mm. length of 12-mm. diameter Alnico rod fastened to a pulley which is connected to a bicycle wheel race screwed to the bottom of a box; the latter can slide forward and backward, being guided by tracks screwed to the table. A stop is provided on the latter to limit the forward movement of the box and arrest it in its normal working position where it supports the receiver. The entraining magnet rod then coincides with the stirrer rod which should revolve in the front part of the flask (away from the electrodes). The pulley is belt-driven by a small motor fastened at the back of the box. A safe speed for the stirrer is 600 r.p.m.

Automatic Solvent Mixer. This apparatus, *J* in Figure 1, is shown in greater detail in Figure 3. It comprises mixing flask *A* and solvent saturator *B*. Flask *A* is made by adding outlet *C* to a long-necked, flat-bottomed flask. The body of *B* is constructed like a Vigreux column.

At the beginning of a run, flask *A* is completely filled with 75% methanol (methanol C); 100% methanol (methanol A) is introduced into the flask through adapter *D* at a constant rate while magnetic stirrer *E* is operating, driven by *F*. The solvent flowing out of the flask through *B* is thus gradually and evenly changing from the initial 75% methanol to increasingly more concentrated alcohol. The alcohol leaving the flask drips slowly down through a height *GH* of 2,2,4-trimethylpentane located in *B*. The 2,2,4-trimethylpentane–equilibrated alcohol collects under *G* before flowing through *I*, and from there, through *L* and *M*, to the column.

To prepare the device for a new run open stopcock *J* and remove adapter *H*, allowing *B*, *I*, and *M* to empty. Set stopcocks *K* and *L*, and allow methanol B to flow through *K*, *L*, and *I*; alternately closing and opening *J*, flush the base of *B*. Close *J* and allow alcohol to rise up to *G*. Adjust *L* to stop flow of alcohol. Fill *B* from *G* to the top with 2,2,4-trimethylpentane. Remove adapter *D*, empty the flask, rinse with methanol C, and fill with this solvent. Reconnect *D* and *H*.

Buret. The semiautomatic motor-driven buret (Figure 3) consists of a piston sliding in a tubing body, *N*, which is cemented in block *O*. *O* is fastened to the 0.25-inch aluminum base plate by leveling screws and aligned with the piston drive comprising piston shaft *P* and screw *Q*. Motion of the piston is induced when the drive is made to revolve; *Q* then screws or unscrews itself in nut *S*, thus causing the piston drive to move forward or backward, depending on the rotational direction. Motor *T* actuates this mechanism through a gear train: Gear *U*, directly on the motor shaft, is driving gear *UA*. The latter shares a common shaft with worm gear *UB* which drives worm gear *UC*. *UC* bears a square, central hole which fits over square bar *R*; *UC* thus induces the bar to revolve, allowing it to slide freely through the hole.

Details of the piston head are shown at the right in Figure 3. It is made of three $^1/_8$-inch thick Teflon disks sandwiched between washers and held together by screw *V*. The latter fits the threaded collar of *W*, a hollow knob presenting an off-centered slot *X*. Pin *Y* of piston shaft *P* can be inserted through the

side of slot *X* but cannot be disengaged from *W* when the piston head is aligned with the piston shaft, since *Y* is larger than the centered part of the slot. However, it can revolve freely inside *W* without causing the piston head to rotate; the latter is thus merely pushed or pulled. Slack is provided in the centered part of the slot to allow for misalignment of tube *N*. *W* is used as a chuck when turning to size the Teflon disks on the lathe. Coasting of the motor is prevented by friction brake *Z* on the motor shaft.

A cam located at the end of the shaft common to gears *UA* and *UB* actuates microswitch *MS-C*, sending impulses to the alkali-recording counter. One count corresponds to $^1/_{60}$th of a turn of the screw or a $^1/_{540}$-inch movement of the piston; with the $^5/_8$-inch Trubore tube used, one count is equivalent to 9.70×10^{-3} ml. Checking the reproducibility of volume delivery has shown a maximum error of 3×10^{-3} ml. or approximately one third count; when 0.01*N* alkali is used, this is equivalent to 3×10^{-8} mole.

A wiring diagram of the buret is shown at the lower left of Figure 3. Parts *SW-R*, *SW-S*, *SW-T*, *MS-U*, and *MS-V* are switches denoted as *R*, *S*, *T*, *U*, and *V* in Figure 1. Parts denoted *HW* and *RW* are, respectively, the microvalve admitting alkali to the buret and the rectifier already described.

Reagents.

Methanol A. Nichols methanol, reagent grade, No. 1212. Reflux over sodium hydroxide. Distill, collecting from 64.0° to 65.0° C. Keep in reservoir *L*, Figure 1.

Methanol B. Mix 75 volumes of methanol A with 25 volumes of distilled water. Saturate by shaking with excess 2,2,4-trimethylpentane and pour into reservoir *M*, Figure 1, without removing excess hydrocarbon.

Methanol C. Mix 75 volumes of methanol A with 25 volumes of distilled water. Keep in a glass-stoppered bottle.

Methanol Recovery. Reflux methanol used to pack, wash, and elute the column over sodium hydroxide. Redistill, collecting from 64° to 72° C. Use in the preparation of the silane-treated silicic acid.

Chloroform. Distill Fisher certified reagent C-298. Collect from 60.0° to 60.8° C. Keep in brown glass-stoppered bottle. This reagent should be acid-free.

2,2,4-Trimethylpentane. Phillips, pure grade. Redistill with 45-cm. Vigreux column, collecting from 98.0° to 98.6° C.

2,2,4-Trimethylpentane Recovery. Shake repeatedly with water the 2,2,4-trimethylpentane used in the preparation of silicic acid; reflux with 1*N* sodium hydroxide for several hours; decant, dry, and fractionate as above. Check: when refluxed with water, the product should leave the water neutral to bromocresol green.

Titrating Solution. Reflux 1 liter of aldehyde-free 95% ethanol while bubbling nitrogen through the boiling liquid; let cool under nitrogen. Add 0.46 gram of clean sodium; let dissolve while bubbling nitrogen. Prepare 1 liter of 10% sodium chloride solution in distilled water; reflux the solution while bubbling nitrogen and let cool under the same conditions. Mix the two solutions in nitrogen-filled reservoir *X* (Figure 1) and stopper immediately. The strength of this solution will remain remarkably constant for several months.

Silane-Treated Silicic Acid. Sieve Assembly. This apparatus is made from parts of U. S. Standard sieves assembled in the following way: cover, No. 170, No. 230, and base.

Flask. The center neck of a standard-taper, 1-liter, three-necked flask is fitted with a Trubore, all-glass stirrer (Scientific Glass Apparatus Co., Inc., No. J-2169). One of the side necks is connected, through a right-angle, stopcock-fitted, standard-taper connecting tube, to two 300-mm. high drying jars in series. The first is filled with calcium chloride, the second with soda lime. The other neck holds a 150-ml. dropping funnel fitted with a rubber stopper connected to a calcium chloride–filled drying tube.

Procedure. With this procedure a 65-gram batch is prepared, enough to perform 60 successive analyses. The silicic acid is readily recovered and re-used. Usage of a batch is limited only by mechanical losses and by the formation of fines which have to be removed occasionally by sieving.

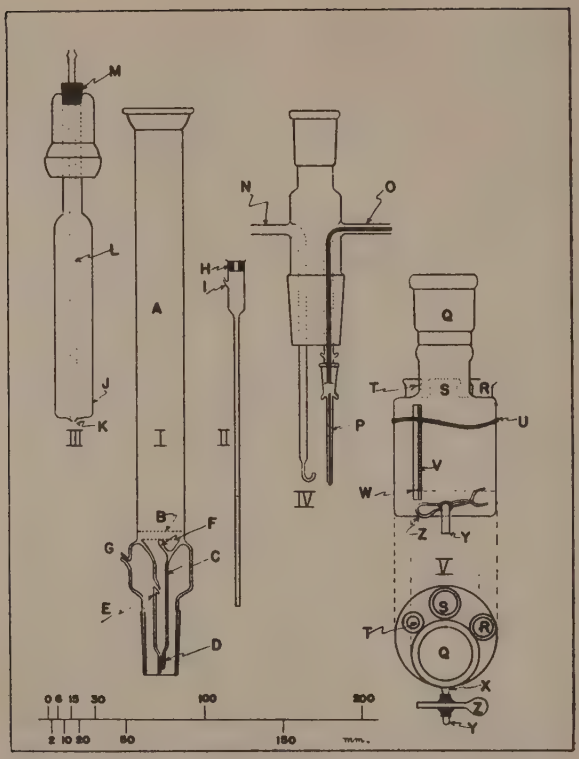

Figure 2. Parts of column assembly

I. Column proper
II, III, IV. Adapters
V. Receiver
A. Body of column, 1-inch Trubore tubing
B. Coarse fritted-glass disk, 5 mm. thick
C. Outlet tube, ring-sealed, funnel-shaped
D. Tip
E. Vent
F. Small piece of rod
G. Outlet for nitrogen bubbled through receiver
H. Teflon plug
I. Vent
J. Outer tube
K. Tip created by blowing out center of *J* and reducing hole produced to 1-mm. diameter outlet
L. Inlet tube
M. Cork
N. Nitrogen Inlet
O. Alkali inlet
P. Delivery tip. Bore corresponds to 47-gage steel wire
Q, T. Necks
R. Neck fitted with calomel electrode (Beckman 11-505-80A)
S. Neck fitted with glass electrode (Beckman 11-505-75)
U. Elastic band
V. Scale, thin strip of white, rigid plastic, engraved 1-ml. graduations
W. Permanent mark
X. Outlet
Y. Outlet
Z Pinch clamp

Sieve silicic acid (Mallinckrodt's No. 2847) using the prepared assembly. Three granular fractions are obtained: coarse (22%), medium (15%), and fine (63%), from which only the medium fraction is used. Spread 75 grams of the latter over a 15-cm. Petri dish, and dry over phosphorus pentoxide in vacuo, using a good mechanical pump and establishing the vacuum slowly to prevent sudden bursting of air pockets within the powder. Carry out the drying to constant weight, renewing the drying agent if necessary. Transfer the weighed powder to a wide-necked 250-

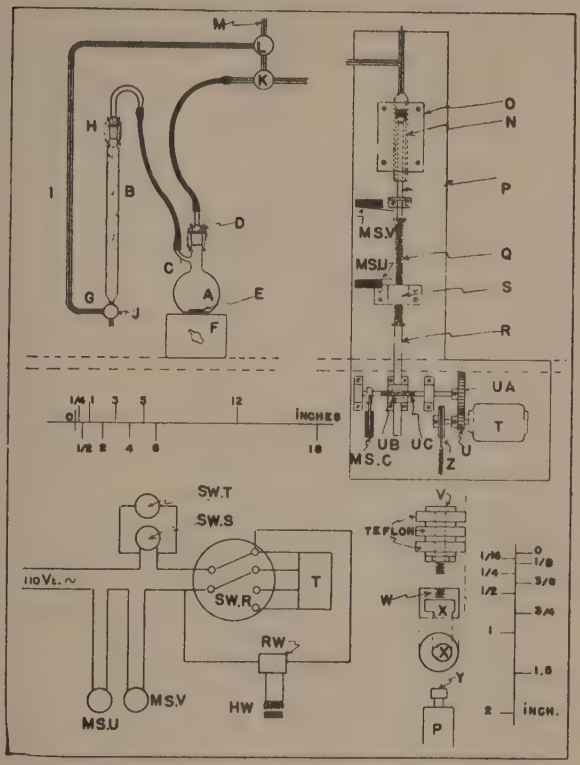

Figure 3. Solvent mixer (top left), semiautomatic buret (top right), wiring diagram of buret (bottom left), and buret piston (bottom right)

A. Mixing flask made by adding outlet *C* to long-necked, flat-bottomed, standard-taper 24/40 250-ml. flask
B. Solvent saturator constructed like Vigreux column
C. Outlet
D, H. Adapters
E. Magnetic stirrer driven by *F*
F. Motor, drives *E* (Mag-mix, Precision Scientific Co., No. 65904)
G. Lower level of 2,2,4-trimethylpentane
I. Capillary tubing
J, K, L. Stopcocks
M. Capillary tubing
N. Tubing body, $^{3}/_{8}$-inch Trubore
O. Lucite block
P. Piston shaft P, $^{3}/_{8}$-inch steel rod
Q. Screw, 0.5-inch 13-R.H.-bar
R. Square bar
S. Nut
T. Motor, Type N8-Y-12, 115-volt, a.c., $^{1}/_{150}$ h.p. (Bodine)
U. Gear (Boston QBH-16)
UA. Gear (Boston QB-48)
UB. Worm gear (Boston LVHB)
UC. Worm gear (Boston G-1044)
V. Screw
W. Hollow knob
X. Off-center slot
Y. Pin of piston shaft *P*
Z. Friction brake on motor shaft
MS-C. Microswitch
SW-R, SW-S, SW-T, MS-U, MS-V. Switches, denoted *R, S, T, U,* and *V* in Figure 1
HW. Microvalve admitting alkali to buret
RW. Rectifier, 30-volt, d.c.

ml. glass-stoppered bottle. Add rapidly a volume of water corresponding to 6% of the weight of silicic acid and stopper immediately. Shake and tap the bottle vigorously for 5 minutes and place for 15 minutes on a roller-mixer.

The rest of the operation must be carried out under a very efficient hood, using gas mask and gloves when handling aggressive dichlorodimethylsilane (Dow Corning). The latter should be cooled a few hours in the refrigerator before use.

In a glass-stoppered 200-ml. measuring glass, pour 6 ml. of silane for every milliliter of water used in humidifying the silicic acid. Add dry 2,2,4-trimethylpentane to the 100-ml. mark, stopper immediately, and shake cautiously.

Remove the dropping funnel from the prepared flask and pour 250 ml. of dry 2,2,4-trimethylpentane into the flask; switch on the stirrer and place a solids funnel over the open neck. Add the humidified silicic acid by portions and replace the dropping funnel. Pour the silane solution into the latter, stopper, and run the liquid regularly into the contents of the flask over a 30-minute period. Transfer the mixture, using 2,2,4-trimethylpentane for rinsing, to a 14-cm. Büchner funnel equipped with filter paper and a 2-liter suction flask connected to a water aspirator. Wash the product repeatedly to remove unreacted silane using approximately 400 ml. of 2,2,4-trimethylpentane in all. Remove the Büchner funnel, and add water to the filtrate to destroy silane. Transfer the cake to a 1-liter beaker containing 250 ml. of recovered methanol and stir vigorously to produce a slurry which is poured over a 14-cm. Büchner funnel equipped like the previous one; apply suction and filter slowly, taking care to keep the cake submerged by adding small portions of recovered methanol until the filtrate is no longer acid to bromocresol green (about 1 liter in all). Transfer the cake to a 15-cm. Petri dish; protect from dust while letting air-dry overnight.

Sieve the powder in the sieving assembly described above, retaining the medium fraction. Tenacious acidic impurities must be removed by applying to 24-gram batches of the powder the procedure described later under Column Mixture and Packing, then connecting the packed column to the methanol A reservoir and letting 400 ml. of this solvent percolate at the rate of 100 ml. per hour.

Remove adapter III (Figure 2); remove paper disks, and fill the column with recovered methanol; using the spiral stirrer, produce a slurry. Transfer to a Büchner funnel and filter under suction. Cover and let air-dry overnight. Keep 24 hours in a vacuum desiccator over phosphorus pentoxide.

To recover the powder after an analysis, follow the procedure described in the last paragraph.

ANALYTICAL PROCEDURES AND TECHNIQUES

Column Mixture. Place 8.0 ml. of 2,2,4-trimethylpentane in a 250-ml. glass-stoppered bottle. Add 23.5 grams of silane-treated silicic acid and stopper. Alternately shake and tap the bottle for at least 5 minutes; place on a roller-mixer for 15 minutes.

Pour the powder obtained into a 250-ml. beaker containing 65 ml. of methanol B and stir rapidly to expel air bubbles.

Packing. Packing accessories such as paper disks, packing piston, and spiral stirrer have been described previously (*16*).

Pour the slurry into the glass column using a wash bottle containing methanol B to assist in the transfer. Insert spiral stirrer immediately and work it up and down in long strokes to homogenize the slurry. Then, starting from the bottom and gradually higher up, work the stirrer in short rapid strokes forcing air bubbles to rise and leave the slurry. Allow the slurry to settle by gravity; when settling has almost ceased, make sure that a height of at least 3 cm. of free supernatant liquid is left before inserting a blotting paper disk obliquely until it is completely submerged in the liquid. Insert the packing piston and lower it carefully, pushing the disk in firm contact with the packing. Remove the piston slowly. Add about 5 ml. of methanol B and place a second disk in a similar manner.

Table I. Part of Typical Record Chart

Alkali, Counts		Time, 0.01-Min. Increments			
Total (c)	Addition (δc)	Total (t)	Interval (δt)	$\delta t/\delta c$	Eluted Volume, Ml.
...	...	0	...	...	0
10	10	2648	2648	265	46
20	10	3080	432	43	...
40	20	3835	755	37.7	...
70	30	4613	778	26	...
100	30	4880	267	9	...
170	70	5107	227	3	...
270	100	5327	220	2	Peak
350	80	5571	244	3	...
370	20	5702	131	7	...
380	10	5806	104	10	...
390	10	6011	205	20.5	...
400	10	6611	600	60.0	115
410	10	7011	400	40.0	...
420	10	7249	238	23.8	Receiver emptied
440	20	7512	263	13	...
470	30	7701	189	6	...

Loading. Remove excess methanol B by suction, leaving about 1 ml. over the top paper disk. Allow the alcohol to drain from the paper disk by gravity. With an automatic micropipet (1809 self-adjusting transfer, Lambda-Pette-Research Specialties Co., Berkeley 7, Calif.) add 0.75 ml. of the sample solution. While this drains, place adapter III, unclamped, on the column and connect it to reservoir M. As soon as the sample has cleared the disk, add 0.75 ml. of methanol B, allow it to drain, add another 0.75 ml., and so on. In all, use four washings before connecting adapter III with the source of eluting solvent and clamping it on the column.

In the above sequence, the following rules are very important:

The liquid should always be allowed to drain by gravity.

The sample solution, the methanol B immediately preceding, and that immediately following the addition of the sample should drain until the clearly visible edge of the descending meniscus just coincides with the upper edge of the paper disk. In each case, the subsequent addition of liquid must be made just when the edge of the meniscus fades out.

For the remaining two washings the next addition of methanol B is made when the preceding one has cleared the center of the paper disk, leaving the edge still wet.

All additions should be swift and deliberate. When the sample is being added, the tip of the pipet should be located centrally and as close as possible to the paper disk.

Development, Elution, and Titration. At the time this stage of the analysis is reached, the receiver is in working position, filled to mark W (Figure 2) with methanol B at pH 8.7; the stirrer and the pH meter are in operation. Nitrogen has been bubbling through the receiver for at least 0.5 hour and chronometer G (Figure 1) has been reset to zero.

As soon as the flow of eluting solvent is admitted to the column, chronometer G is switched on and 10 counts of alkali are added to the receiver. This is gradually neutralized by acid eluate causing the initial deflection of the pH meter needle, about 0.8 unit, to decrease. The time at which the pH meter needle reaches its initial position (8.7) is noted, and another 10 counts of alkali added to the receiver. Except for an occasional check of the rate of flow and for emptying the flask to mark W whenever the elution of an acid is completed, these two simple steps—adding alkali and noting the time corresponding to the end point—form the pattern of the whole analysis. After a new addition, before the recurrence of the end point, the operator determines for the preceding addition the time-alkali ratio, $\delta t/\delta c$, indicating the concentration of the acid eluted. Guided by this information, the addition of alkali is proportioned to the intensity observed. Thus, 30, 50, or even 100 counts of alkali may be added if the concentration is high and still rising; on the other hand, the size of the addition is reduced when, as indicated by the $\delta t/\delta c$ ratio, the concentration is low or declining. For convenience in calculating $\delta t/\delta c$ at a glance, all additions are made in multiples of 10 counts. Band

boundaries corresponding to lowest acid concentrations are indicated by maxima observed in the $\delta t/\delta c$ values. These maxima must be determined as accurately as possible. Consequently, as soon as $\delta t/\delta c$ is observed to rise, each successive addition is limited to 10 counts only. Since periods separating successive end points become increasingly longer in the band boundary region, no difficulty is encountered in securing accurate time readings. No advantage is gained by reducing the size of single additions below 10 counts.

Table I shows the first section of a chart recorded during a typical run carried out on a mixture containing all even acids from C_{12} to C_{24}. Lauric acid appeared 26.48 minutes (the chronometer dial is marked in 0.01-minute graduations) after the onset of elution. The threshold volume (column 5) was 46 ml. as read on the receiver scale. After a few cautious additions of alkali, $\delta t/\delta c$ decreased to a low value, indicating a very strong band. Consequently, the subsequent additions were made larger and larger until the descending slope of the band, as indicated by increasing $\delta t/\delta c$, was reached. The successive additions were then reduced to 10 counts. As soon as the appearance of the C_{14} band became evident, the flask was emptied to mark *W* in a few seconds by simultaneously pinching clamp *Z* and the rubber tube on nitrogen outlet *G*, switching off the stirrer momentarily to permit adjustment of the level. Addition of alkali was then resumed, and the analysis of the following bands was carried out in an identical manner.

Two changes of the pH value taken as end point are made to take into account specific neutralization pH values. These have been determined for the different acids, under the conditions of the analysis, by using a procedure described below. Such changes should never be made in the band boundary regions but somewhere in the middle of the appropriate band where no great accuracy of $\delta t/\delta c$ is required. The first change is made in the C_{16} band (from 8.7 to 8.9), and the second in the C_{18} band (from 8.9 to 9.1).

Routine Analytical Procedure. Prepare the column mixture and pack the column as directed above.

Load with 0.75 ml. of a chloroform solution containing approximately 10 mg. of pure lauric acid per milliliter.

Elute with methanol B, directing the flow of this alcohol from reservoir *M* through clamped adapter III at a rate of approximately 2 ml. per minute, collecting the eluate in a beaker.

After approximately 120 ml. of eluate have been collected, prepare the receiver as follows: Fill to mark *W* with methanol B, adding a few drops of 20% sodium chloride solution in water. Put the 20-mm. Teflon-covered magnetic stirrer in place, and set the receiver in working position. Switch on the stirrer, direct the flow of nitrogen through the receiver, and switch on the pH meter.

After approximately 15 minutes, add enough alkali to bring the pH up to 8.7. Stop the stirrer and empty the flask to mark *W*. Switch on the stirrer and add 10 counts of alkali. Note the volume of eluate necessary to bring the pH back to 8.7. If this volume is less than 40 ml., empty the flask to mark *W* and add another 10 counts of alkali. When the volume of eluate necessary to bring the pH down to 8.7, after an addition of 10 counts of alkali, is 40 to 50 ml., the column conditioning is completed. The flow of methanol B is then arrested.

Unclamp adapter III and follow the directions given for loading and development, elution, and titration. After the column is loaded, the automatic solvent mixer is put into operation and the flow of eluting solvent directed through adapter III. The indicator in flow meter *E* (Figure 1) is set and maintained at 8.5, which corresponds to approximately 2 ml. per minute. Occasional small readjustments of the rate of flow should not be made in the region of the band boundaries.

After completing a run, refill the buret to avoid sticking of the piston to the glass body.

Empty the glass column and clean it, first by removing all silicic acid, then by filling it with 1*N* sodium hydroxide solution which is allowed to percolate through the fritted-glass plate; this is replaced by hot water, followed by 1*N* hydrochloric acid, more hot water, and finally recovered methanol. Dry in an oven.

Blank Curve and Alkali Standardization. Experience acquired over 2 years of almost daily use of the present method has shown a high consistency of the blank curve correction values and a remarkable stability of the titrating alkali solution. Both require only an occasional check, which is effected in one single operation. The procedure is based on the fact that the threshold volumes are fairly constant, regardless of the composition of the mixture analyzed. Averages of these volumes for a considerable number of determinations are given below, along with the respective band-width volumes.

Acid	Threshold Vol., Ml.	Band-Width Vol., Ml.
C_{12}	45	70
C_{14}	115	70
C_{16}	185	75
C_{18}	260	75
C_{20}	335	60
C_{22}	395	60
C_{24}	455	55

For the determination of the blank curve, a blank analysis is made, using 0.75 ml. of chloroform to load the column. The complete procedure described above for loading, conditioning, and developing the column is applied in every detail. However, as soon as the volume of eluate corresponding to the threshold volume (115 ml.) for C_{14} is collected, the flow of eluting solvent is arrested by closing valve *N*, Figure 1. The total amount of alkali (counts) needed to maintain the pH at 8.7 up to that moment is the blank correction corresponding to C_{12}.

When the blank correction has been secured, the flow of nitrogen is substantially increased, the stirrer is switched off, neck *T* (Figure 2) is uncorked, and 0.75 ml. of a freshly prepared solution of pure lauric acid is added to the receiver contents with the aid of an automatic micropipet. Neck *T* is immediately stoppered, the flow of nitrogen reduced to normal, the stirrer switched on, and alkali added until the pH is restored to 8.7. The solution used is made from about 70 mg. of carefully weighed lauric acid dissolved in 5 ml. of methanol A.

From the weight of acid used and the amount of alkali necessary to bring back the pH to 8.7, the titer of the alkali, expressed in counts per millimole (or milligram) of acid, is determined. The receiver is emptied to mark *W* in the usual manner, valve *N* (Figure 1) is opened, and the elution resumed. This time, 75 ml. of eluate are collected. The procedure for the determination of the blank correction and alkali titer corresponding to the other acids is entirely similar, except that the standard acid solutions used are made in chloroform from C_{16} on. Also, the pH value taken for the end point is changed twice, as shown under Elution and Titration.

The volumes eluted correspond each time to the respective band-width volumes given below. Experience has shown that the normality of the titrating alkali, as determined under the above conditions, is not identical for each acid. Since these determinations are made under conditions duplicating those of the routine analysis, the titers corresponding to each acid should be used in calculating the analytical results. The problem is greatly simplified by the fact that a simple relationship exists between the different normalities. Expressing that found to correspond to palmitic acid as 100, the specific normalities for the acids from C_{12} to C_{24} are as follows:

Acid	Relative Sp. Normality of Alkali
C_{12}	99.5
C_{14}	100.5
C_{16}	100
C_{18}	99.5
C_{20}	99.5
C_{22}	97.5
C_{24}	97.5

It is thus only necessary to determine the titer corresponding to pure palmitic acid and to calculate the others from the above relative values.

The average value of the blanks resulting from a series of determinations is given below.

Volume Eluted, Ml.	Blank (Counts)
115	13
185	8
260	12
335	15
395	11
450	10
520	12

Plotting these values provides a blank curve allowing the correction for any given volume interval to be estimated.

Blank values were found to vary not more than 1 or 2 counts for each case examined and the above averages have been successfully used for months.

Specific Neutralization pH Values. These values were determined by using a procedure differing from that described for the determination of specific titer values only in that complete potentiometric titration curves were established for each acid. The specific pH values were then found from these curves in the usual manner. The use of these values in the detection of end points increases appreciably the sensitivity of the pH meter to changes in hydrogen ion concentration and is conducive to higher accuracy. Although the pH values found differed with each acid, only three values are used in the present procedure to take these differences into account. The selected values are close enough to the actual ones and the simplification does not involve any appreciable loss in sensitivity except in what concerns lauric acid. In this case, the initial pH value, 8.7, is appreciably different from the specific value, 8.2, found for the acid; results obtained for lauric acid are thus, as a rule, somewhat less reliable.

Calculations. The minimum alkali increment being 10 counts, the maxima for the $\delta t/\delta c$ ratios as observed do not correspond exactly to the band boundaries. The final c values are obtained by using a simple graphical interpolation procedure, plotting the inverse of $\delta t/\delta c$ against the corresponding c values obtained in the immediate neighborhood of the observed maxima. The interpolated c value corresponding to the example in Table I is 403 counts. The correct c values having thus been established, the amount of alkali corresponding to each band is obtained by difference; the blank correction corresponding to each band volume is then applied.

The resulting corrected amounts of alkali corresponding to each acid are expressed in counts. By using the specific titers and the appropriate general conversion factors, counts are converted to millimoles or milligrams of acid. Special cases, involving very small amounts of component acids are dealt with below.

EXPERIMENTAL

Acid Mixtures. Results obtained from synthetic acid mixtures (A and C) and from unknown mixtures (B and D) are presented below. Mixtures A and C were made using pure acids with corrected melting points and reported melting points (*6*) as follows:

Acid	Corrected M.P., ° C.	Reported M.P., ° C.
C_{12}	43.7	43.5
C_{14}	55.2	54.4
C_{16}	62.5	62.9
C_{18}	69.6	69.6
C_{20}	75.2	75.4
C_{22}	80.4	80.0
C_{24}	83.9	84.2

From C_{12} to C_{18} included, these acids were obtained by carefully distilling the corresponding Eastman Kodak (white label) methyl esters in a Podbelniak semiautomatic microanalyzer, saponifying the constant boiling fractions, and recrystallizing the recovered acid from aqueous ethanol and aqueous acetone. The C_{20} and C_{22} acids were both synthesized by repeatedly applying a known procedure (*17*) starting from pure stearic acid. Lignoceric acid was synthesized from pure behenic acid by converting it to its methyl ester, reducing it to the corresponding alcohol with lithium aluminum hydride, and applying from there on the method of Bleyberg and Ulrich (*1*). The final yield in pure lignoceric acid was slightly better than 80% calculated on the methyl behenate used (10 grams).

Mixture B was obtained by submitting about 5 grams of herring oil to methanolysis and treating the resulting methyl esters with an excess of potassium permanganate in boiling acetone. After

Table II. Results from Mixture A Containing Acids from C_{12} to C_{24} in Unequal Amounts[a]

Acids	Theory, Mg.	Found, Mg.	Recovery, %	Volume Eluted, Ml.	
				Total	Band
C_{12}	1.08	1.12	103.7	102	60
C_{14}	5.31	5.32	100.2	195	73
C_{16}	11.08	11.09	100.2	244	69
C_{18}	17.52	17.30	98.7	311	67
C_{20}	18.18	18.13	99.7	368	57
C_{22}	9.72	10.02	103.1	428	60
C_{24}	3.94	3.91	99.2	485	57
Total	66.83	66.89			

[a] Total time, 4 hours, 13 minutes.

Table III. Results from Mixture B[a] and Mixture C[b]

Acids	Mixture B				Mixture C	
	Run 1		Run 2			
	Found, mg.	Composition, %	Found, mg.	Composition, %	Found, mg.	Composition, %
C_{12}	0.94	2.0	0.94	2.0	0.74	1.6
C_{14}	13.23	28.2	13.12	28.2	13.00	28.0
C_{16}	27.82	59.0	27.68	59.4	27.82	59.9
C_{18}	3.63	7.7	3.63	7.8	3.63	7.8
C_{20}	1.46	3.1	1.24	2.6	1.25	2.7
C_{22}	0	0	0	0	0	0
C_{24}	0	0	0	0	0	0
Total	47.08	100.0	46.61	100.0	46.44	100.0

[a] Mixture of saturated acids from herring oil.
[b] Synthetic mixture made to represent composition found for mixture B

excess oxidant and manganese dioxide had been destroyed with potassium bisulfite, the mixture was acidified and extracted with chloroform and the dried chloroform solution was percolated through a column of alumina until acid-free. The chloroform solution then yielded on evaporation the methyl esters corresponding to the saturated acids originally contained in the sample of herring oil (*15*). Complete removal of unsaturated com-

ponents was checked (iodine value); saponification then led to the free acids from which a 70 mg. per ml. solution in pure chloroform was prepared.

For mixture D a 1-gram sample of herring oil was submitted to methanolysis. The resulting methyl esters were completely hydrogenated in 1 liter of 95% ethanol at room temperature using platinum dioxide as catalyst. The acids were obtained from the saturated esters through saponification, and a 70 mg. per ml. solution of these acids in chloroform was prepared.

DISCUSSION

Results. The results shown in Tables II, III, and IV were obtained by performing the analyses in a room where the temperature was automatically maintained at 25° ± 1° C.

In illustrating a chromatographic method of this type, the presentation of results obtained with mixtures of components in about equal amounts is unrealistic and might be misleading. Cases corresponding to such mixtures are very rarely met in practice, but the performance of any method will be much better, generally speaking, with this type of mixture than with highly disproportionated ones, such as mixture A in Table II. In this example, the recovery obtained for lauric acid, 103.7%, although not uncommonly good for such small quantity, is admittedly better than average.

As stated previously, the error on minor components (1 to 3% of total mixture) is apt to reach 20% for a single determination, owing to small systematic errors which bear heavily on the results obtained for the minor components. If a degree of precision comparable to that obtained with major components is desirable, the following method is applied: A synthetic mixture, made to represent the composition found for the unknown, is prepared and analyzed. The results are then used to correct the previous ones. The method is based on the fact, illustrated by duplicate runs in Table III and Table IV, that the chromatograms from a given mixture are quantitatively reproducible within narrow limits. Experience has shown that the correction applied should be not the whole difference between "unknown" and "synthetic" compositions found but only half that difference. In the case at hand, the corrected composition for C_{12} is thus 2.2%.

In general, less complex mixtures lead to more accurate results. They also require lesser amounts of sample material. An average of 7 mg. per component acid has proved adequate in determining total sample size.

A comparison of volumes eluted (Tables II and IV) shows a good consistency of band volumes; with total and threshold volumes the consistency is even better.

When acids in the series are missing entirely or present in very small amounts (from 0 to about 0.5% of the total mixture), the band immediately preceding the missing or feeble one stretches somewhat beyond the average limits given above. If the following acid is completely absent, the band will stretch 10 to 12 ml. beyond the normal value. If a very small amount of the next acid is present, a distinct band may not form but trailing of the preceding band will occur. An example is given in Table IV, where the band volume for C_{22} is abnormally long. A systematic study of appropriate synthetic mixtures has established the following rule: If a well-defined band trails beyond the corresponding average band volume by about 10 ml. only, the next higher even acid is absent; any acid eluting immediately beyond

this point is taken, less the appropriate blank correction, as the next higher acid. In the example at hand one is thus justified in taking as behenic acid that which has eluted with the first 72 ml. of effluent; the acid contained in the extra 12 ml. is then taken as lignoceric acid.

Table IV. Results from Mixture D[a]

Acids	Run 1			Run 2		
	Found, mg.	Composition, %	Band volume, ml.	Found, mg.	Composition, %	Band volume, ml.
C_{12}	0.73	1.3	60	0.52	0.94	61
C_{14}	3.11	5.6	52	3.14	5.7	62
C_{16}	14.93	26.8	64	14.93	27.1	68
C_{18}	11.18	20.0	61	10.88	19.8	63
C_{20}	12.08	21.6	62	11.76	21.4	62
C_{22}	13.77[b]	24.7	84[b]	13.77[b]	25.0	83[b]
C_{24}	...	<1	..	...	<1	..

[a] Made of hydrogenated total fatty acids of herring oil.
[b] Limiting to normal band volume, result is 13.26 mg. in each case.

The final composition obtained for mixture D as a result of the application of this rule is shown in the first column of Table V as the average for runs 1 and 2.

The composition of mixture B (run 2) was recalculated, using as described the data from synthetic mixture C. The corrected composition is shown in the second column. It was estimated from data obtained through analysis of synthetic mixtures that

Table V. Composition of Herring Oil Sample Calculated from Chromatographic Data Obtained from Mixture B[a] and Mixture D[b]

Acids	Mixture D (Run 2), %	Mixture B, %	Herring Oil, %	
			Saturated	Unsaturated
C_{12}	2.20	1.12	0.43	0.69
C_{14}	28.30	5.65	5.55	0.10
C_{16}	59.1	27.00	11.58	15.42
C_{18}	7.8	19.90	1.53	18.4
C_{20}	2.6	21.50	0.51	21.0
C_{22}	0	24.00	0	24.0
C_{24}	0	0.79	0	0.79
Total	100.00	100.00	19.60	80.40

[a] Hydrogenated acids.
[b] Saturated acids.

the latter type of corrective procedure decreases the maximum error on minor components (1 to 3% of the total mixture) to less than 5% and that on major components ($\geq$ 10% of the total mixture) to less than 1%. Discrepancies between original values (run 2, Table III) and corrected values (second column, Table V) are, except for lauric acid, smaller than 1%.

The third and fourth columns in Table V show the composition of herring oil fatty acids obtained by combining the values in the first two columns; the percentage of total saturated acids (19.6%) was determined by weighing the saturated acids (mixture B) obtained as described by the method of Schuette and Dal Nogare (*13*) from a 5-gram sample of oil.

Equipment. The capacity of the piston microburet, about 22 ml., was made larger than in commercial instruments to permit the use of weaker titrant. A higher degree of precision is thus attained and errors arising from alkali diffusion through the de-

livery tip are overcome without resorting to extremely fine, easily plugged orifices.

The buret piston and body are easily removed, cleaned, replaced (eventually by another size), and connected to any other titrant supply. Removing the column thus provides a convenient general purpose installation for cases requiring precision titration of small samples.

The complete apparatus applies, with minor modifications, to the chromatographic separation of the lower aliphatic acids (*16*).

Mixing flask *A* in the solvent mixing device used (Figure 3) is similar to one proposed by Bock and Ling (*2*) but was developed independently.

Band volumes (Tables II and IV) show the remarkable effect attained by the proper combination of initial solvent volume and concentration which brought the successive bands at almost regular intervals. The initial solvent volume used was measured by slipping the magnet stirrer in the empty flask, filling the flask to the brim with water, and fitting it with adapter *D*, the tip of which had been plugged. The volume of the water trapped in the flask up to the tip of the side arm was 262 ml. A careful check should be made of the initial solvent composition. While a small increase in the water content would not affect results unfavorably, the reverse would lead to poorer separations. The density of the methanol C used in the present work was 0.883 at 25° C. Methanol B must not be substituted.

Column Mixture. Early attempts to procure the promising Mealorub first described by Boldingh (*3*) met with obstacles also reported by other workers (*14*). The column mixture of kieselguhr and paraffin oil proposed by Howard and Martin (*8*), along with their procedure for silane treatment of the column material, did not seem to offer a degree of definition conducive to reproducibility. Consequently, a well-defined granular fraction from a controlled commercial silicic acid was selected as a starting material, and a standardized procedure for the silane treatment was evolved.

Selection of the adequate granular fraction of silicic acid resulted in columns sufficiently porous to allow the use of a relatively small hydrostatic head, thus eliminating all disadvantages inherent in the use of gas pressure. A practically constant head was provided by using a wide solvent reservoir. The change in level resulting from the withdrawal of the quantity of solvent required by one operation, about 500 ml., corresponded to about 1% of the initial liquid head. Under such conditions, the rate of flow is easily controlled and maintained to a fixed value by occasional resetting of the needle valve.

The amount of silicone material present in the final silicic acid powder is directly related to the amount of water added to the silicic acid prior to treatment with excess dichlorodimethylsilane. A systematic study of the properties of treated powders, corresponding to initial additions of water ranging from 3 to 11%, showed 6% water to be the optimum when separating power, permeability, ease of packing, and column stability were taken into consideration.

Packing and Loading. The sequence of operations described for loading the column with the sample solution resulted from a systematic study involving various solvents and solvent combinations both to make up the solution and to wash it down the column. Care in following the described loading schedule was found of major importance.

On developing the column, a translucent ring appears early at the top, progressing slowly down the first quarter of the column height. Correct manipulations will produce a thin, even ring; a jagged, broad, or lopsided ring indicates either defects in the disk size or shape, or a faulty, uneven loading of the column.

APPLICATIONS

The range C_{12} to C_{24}, covered in a single operation, makes the present method directly applicable to the vast majority of fats, a surprisingly large number of which contain acids belonging to one or both extremes of this range. Among these are the marine oils, fats from the brain, liver, and other organs of many land animals, and fats from the seeds of plants growing in the temperate, tropical, and subtropical zones. Carbon series below C_{12} or above C_{24} are comparatively rare. In the marine oils, they are very sparingly represented, when present at all. Fats containing keto-, hydroxy-, cyclic, and branched-chain acids would not be directly tractable, but these are of exceptional occurrence (7).

The method should be particularly useful in giving quantitative information concerning variations affecting the fatty acid composition of naturally occurring lipides of interest to science and economy; differences arising in the same species of plant or animal are of particular interest in that they may reflect important biological or pathological phenomena.

Among a host of accessible technological problems are those involving control and monitoring of fat fractionating processes, analysis and control of commercially produced fat mixtures, and detection of adulteration in fatty foods and of impurities in samples of fatty acids and derivatives.

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A NEW SPECIES AND TWO NEW RECORDS OF POLYCHAETA FROM EASTERN CANADA[1]

By E. Berkeley and C. Berkeley[2]

Abstract

Two of the three species recorded in this paper (*Ceratonereis scotiae* sp. n. and *Nereis diversicolor* O. F. Müller) were collected some years ago, but hitherto their occurrence has not been noted. The third (*Tharyx marioni* (Saint-Joseph)) was collected recently for the first time in Canadian waters.

Nereidae

Nereis (Ceratonereis) scotiae sp. n.

Three specimens collected littorally by Dr. W. S. Hoar at Mitchell Bay, N.S., in 1939 have been in our possession since then, but remained unexamined until recently. Two of them are complete, the third is incomplete posteriorly. The largest specimen is about 40 mm. long and 4 to 5 mm. wide over the setae. The prostomium is as long as it is wide. It has two pairs of eyes, the anterior pair on the median line and farther apart than the posterior pair. The posterior tentacular cirri reach as far back as the 8th to the 10th setiger. The jaws have six or seven teeth. Paragnaths are entirely absent from the oral ring, excepting faint indications of a single one on VI, on each side, in one specimen. I = 1; II = more or less circular groups of 4 or 5; III = an elongated group of 6 or 7; IV = arc-shaped groups. The dorsal cirri do not extend beyond the dorsal lobes of the notopodia except in the extreme posterior region. The parapodia are three-lobed in both rami in the anterior and median regions (Fig. 1), becoming narrower in the posterior region and with the median lobes considerably diminished. In the dorsal ramus all the setae are homogomph spinigers; in the ventral ramus there are homogomph and heterogomph spinigers and heterogomph falcigers with long knobbed ends (Fig. 2).

We classify this species in the subgenus *Ceratonereis* because paragnaths are absent from the oral ring. It belongs to the division of the subgenus characterized by having parapodia with three notopodial lobes. Of these it comes nearest to *N. (Ceratonereis) costae* Grube, the parapodia being very similar to those of that species throughout the body. The main differences are in the presence of a paragnath on I (*N. costae*, and many other species of its division of *Ceratonereis*, having none), and of the characteristic long-ended knobbed neurosetae.

Nereis diversicolor O. F. Müller. Fauvel (2, p. 344)

This species should have been recorded from eastern Canada long since. We identified it in 1935 in material collected in that year by Mr. H. M. Rogers, formerly of the University of Toronto, at Reversing Falls, St. John

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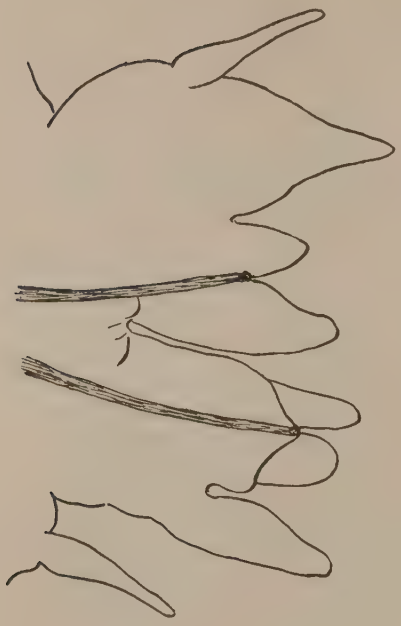

FIG. 1. *Nereis (Ceratonereis) scotiae* sp. n. Median parapodium.

FIG. 2. *Nereis (Ceratonereis) scotiae* sp. n. Heterogomph falciger.

River, N.B. We did not at that time realize the interest of the find and did not record it. This was not, however, the first time the species had been collected in eastern Canada. Dr. A. H. Leim of the St. Andrews Biological Station tells us that he collected it in the Shubencadie River, N.S., in 1922 and that his specimens were identified by the late Professor A. L. Treadwell. In this case too the find has remained unrecorded. The species is widespread in Europe, but we have been unable to find any previous mention of it from North America.[3] It is markedly euryhaline and, for this reason, has formed the subject of many interesting studies. An outstanding morphological peculiarity of the species is the presence of at least one heavy homogomph seta with the endpiece more or less completely fused with the shaft in the *neuropodium* of posterior setigers. Fauvel's figure (133-e) shows a condition of only slight fusion. More advanced and, in our experience, more common stages are shown in our Fig. 3. In the specimens from St. John River fusion is complete (Fig. 3(*a*)). In all other respects they agree closely with Fauvel's description.

[3]*While this paper was in the press we learned from Dr. M. Pettibone of the University of New Hampshire that she has taken N. diversicolor on the coast of both Maine and New Hampshire, but the occurrence has not yet been recorded.*

FIG. 3. *Nereis diversicolor* O. F. Müller. Specialized setae from posterior neuropodia, showing two stages of fusion.

In this connection reference should be made to two other species of Nereidae, *N. japonica* Izuka, the Pacific counterpart of *N. diversicolor*, and *Neanthes lighti* Hartman, which has been confused with *N. japonica*. *N. japonica* is a common Japanese form. It was named by Izuka (6) as a new species in 1908 and was described by him in detail in 1912, but the "*N. diversicolor*" described from Japan by Marenzeller (8) in 1879 is undoubtedly identical with *N. japonica*. The two species are extremely close. It is doubtful, indeed, whether *N. japonica* should not be regarded as a variety of *N. diversicolor*. Both are euryhaline. Both have the specialized neuropodial setae with fused terminations in posterior setigers and the forms of the parapodia in the various body regions are similar, as also are the spinigerous and falcigerous setae. Differentiation is, however, quite definite on the basis of the arrangement of the paragnaths on the ventral surface of the oral ring of the proboscis (Groups VII and VIII). These form a single continuous row in *N. japonica*, whereas in *N. diversicolor* they are arranged in three or four more or less irregular ones (Izuka (7), Pl. 17, Figs. 17, 18).

N. japonica has been recorded from British Columbia (1) and we have identified it in material from the neighborhood of Friday Harbour, Washington, U.S.A., and from the Salinas River, in the Monterey region, California, both sent to us by Dr. R. I. Smith of the University of California. Dr. Smith has utilized specimens from the latter locality, of which he sent us

samples, for embryological (10) and distributional (11) studies, and identified the species concerned in both cases as *Neanthes lighti* Hartman. We have been unable to confirm this identification from Hartman's (4) description of *N. lighti*. All the many specimens from both Friday Harbour and the Salinas River we have examined have the characteristic fused neuropodial homogomph seta, the arrangement of Groups VII and VIII of the paragnaths, and the parapodial forms of *N. japonica*. In the description of *N. lighti*, on the other hand, no mention is made of a specialized fused homogomph seta and the form of the notopodium in median and posterior parapodia is markedly different to that of *N. japonica* and *N. diversicolor*, particularly in respect of the median lobe.

It is remarkable that reproduction in the populations of *N. japonica* studied by Dr. Smith was viviparous (Smith (10)), whereas, according to Izuka (7), breeding occurs in the species in Japan through swarming epitokes. However, it is well recognized that there is considerable power of modification in method of reproduction with variation of environment amongst Polychaeta, and this seems to be a case in point.

Tharyx marioni (Saint-Joseph). Fauvel (3, p. 100)

Three examples of this species were taken by Dr. A. H. Leim, of the St. Andrews Biological Station, in a plankton tow between 20 meters and 1 meter, in Seal Cove, Grand Manan Island, N.B., in August, 1955. All are about 35 mm. long, 1 to 1.5 mm. wide. No species of Tharyx has been recorded previously from eastern Canada, but the form taken by Dr. Whiteaves in the Gulf of St. Lawrence in 1872 and recorded by McIntosh (9) as *Chaetozone whiteavesi* may well be a synonym of the present species. The size is not given, but the general description agrees and the setal characters are those of Tharyx.

Two species of Tharyx were described from Maine by Webster and Benedict (12), *T. acutus* and *T. similis*, both very much smaller than *T. marioni*. Moreover, both these species fail to agree with the definition of Tharyx as generally accepted (see Fauvel (3), p. 99) in that the segment bearing the heavy tentacular cirri and the one immediately posterior to it are non-setigerous and, in the case of *T. similis*, that short stout setae are present as well as capillaries.

The only other Tharyx reported from the east coast of North America appears to be *T. setigera* Hartman from Beaufort, North Carolina (Hartman (5)). This again is a very small species and it has limbate setae.

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THE POTENTIAL OF BRITISH COLUMBIA'S MARINE RESOURCES

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No resource presents more difficulties for the would-be prophet than sheries. It is not only subject to the same economic factors as other ndustries, but it has special problems of its own. These lie in the fact that ie raw material consists of populations of living animals free to everybody o catch, some of them internationally. They occur mainly in the sea. hey are difficult to see and assess. They move about, and they change in bundance largely because of factors over which we have no control. The ctors governing their distribution are as yet imperfectly understood, and emselves unpredictable. Research has made great strides in recent ears, and our knowledge is increasing rapidly and at an increasing pace, ut there is still much more to learn about the sea and how to find and evelop its resources than we have learned in the past.

There can be little doubt that the development of the fisheries resource s a whole has a greater future than a past, but the exact course of that ture is hidden from us. Obviously it would be a very rash man, indeed, ho would pretend to make an accurate prediction. What I have to say will ot represent accepted views, but rather my own personal opinions. In neral, I feel a little bit more optimistic than my advisers, but I feel retty sure I am right.

We have seen that the magnitude of the British Columbia fishing ndustry is great. In 1954, its products had a value of about $70 million. t employed many thousands of fishermen and shore workers. We have lso heard from Dr. MacPhee that the fisheries' share in the value of British olumbia production has declined in the last 15 years, although its actual otal has increased greatly. We have heard him point out the Province's eed for diversified development.

What can we say about the prospects for making fuller use of our sheries resource? On what does this depend? What can we all do to help? should first like to make some general statements, and then, if time ermits, to say something on our more important individual fisheries.

Population increases here and abroad will create a growing demand. realize that I am getting outside the field of a biologist in saying this, but don't think there can be any doubt that the long-term future is one of ncreasing demand. Even if fisheries continue to supply only the same roportion of the world's protein needs, larger quantities of fish will be onsumed. There seems, however, to be some indication that fisheries will e called upon to supply a larger share because the capacity of the world's gricultural land is not unlimited and the increasing demand for food nds to shift land use from animal production to plants which can be roduced in larger quantities. The long-term trend will be towards higher emand, both for home consumption and for export.

Fisheries developed first from those stocks which are easy—and that neans cheap—to find and catch, and from those that are attractive to eat. here are reserves in the sea of species not now used, and to some extent nexploited, and even undiscovered stocks of species now fished. The action

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of demand, associated with large populations, on the development of fisheries is well exemplified by comparison of landings on the two sides of the Atlantic and Pacific Oceans. Quoting FAO's figures for 1953 of a world production of 27 million tons of fish, the North Atlantic produced 8 million and the North Pacific 9 million. In the Atlantic, 5.8 million tons came from the north eastern part close to densely populated Europe, and only 2.2 million from the north west in spite of the fact that there are very large fishing grounds there fished extensively by Europeans as well as North Americans. In the Pacific, 8½ million tons came from the Asiatic side, and only 600,000 tons from the North American. It is interesting to note in passing that the west coast of North America produces about 2% of the world's total, and British Columbia about 1%. The reason why British Columbia has such a large proportion of the North American catch is its highly developed herring fishery which has a big tonnage at a relatively low value. Canada produces half the poundage, but much less than half the value of the North American catch in the Pacific.

The figures just presented emphasize the importance of economic factors in fisheries development. Growth of our fisheries is greatly dependent upon increased demand and on keeping costs low enough to compete, not only with other fisheries, but with other foods. With our high wage levels as compared with many of our international competitors, this means that we must be very efficient. The economists and the businessmen can speak better than a biologist on this phase of the problem, but its importance must not be overlooked either by industry or by administration.

British Columbia's fisheries can be increased if we have the expected increasing demand and if we can use the resource efficiently. We need for this imagination and courage. Let us turn to the question of where we can find greater supplies of raw material. Time does not permit detail, but some consideration of the various sources is necessary.

The salmon fisheries dominate the British Columbian picture with a little bit more than ⅔ of the value. As Dr. Shepard has pointed out, salmon fisheries are very peculiar fisheries of a very special kind which differ very widely from any other of the major fisheries. In the first place, salmon are very easily caught. As a matter of fact, if one went as far as the Russians and fished mainly with traps, they pretty nearly catch themselves. So they are more susceptible to over-fishing than any other major fishery in the world.

There is no evidence that the salmon stocks are taxing the capacity of the sea, because even though these are great fisheries, the poundages of salmon in the North Pacific are rather small when compared with the poundages of cod in the North Atlantic, and they occupy about the same ecological niche. The salmon get just as close to the primary plant production as do the cod. Furthermore, we have evidence that the salmon stocks used to be bigger. All this means that the emphasis is on the fresh water life of the salmon where we must maintain an increased production by regulation and, where possible, by improving the fresh-water environment. These fresh-water conditions can be influenced by man a great deal, and the problem presents a challenge both in a positive and a negative way. We must so organize things that we improve the environment as much as possible to increase the fisheries and avoid as much as possible damaging it by using the water in other ways.

The main purpose of regulation is to see that enough fish get through to pawn. In general, as Dr. Shepard has indicated, our salmon stocks are now t an equilibrium. We have passed the stage of skimming the cream and hey are at an equilibrium with the present fishery and are now tending, ost of them, to increase.

The regulation that has been carried on has been done, I think, xcellently well on the basis of existing knowledge. But the regulation of almon fisheries is quite a complicated subject and we are only now eginning really to learn the most fundamental fact of all, and that is how any salmon need to get through to produce the maximum number of young almon.

Our information in this field is improving rapidly, and I expect that egulations to increase the salmon production will be able to be more ffective as the biologists do their stuff. Research has to bring forth these esults in an applicable form and as that happens, the regulation can mprove. There is no question in this area of strong support from ndustry, fishermen, and operators alike, for conservation measures. As a natter of fact, my own reaction, coming from the Atlantic Coast where here are more rebels than here, is that there is a surprisingly strong upport for conservation in this area.

It is very hard to estimate what optimum regulation can do by itself. Nobody is prepared to make a very firm prediction. However, when we xamine what the salmon catches have been and when we estimate, from vhat knowledge we have, the capacities of areas of fresh water to produce oung salmon (such as the carrying capacity of lakes for young sockeye r streams for fry production) we arrive at a minimum estimate. Nobody hat I have come across has made an estimate of a potential increase of ess than 50%, and some very much more. My own guess is that, if we ould have full knowledge and if we could apply this knowledge quite ffectively, the eventual increase from the best possible regulation is more ikely to be of the order of 100%.

Now, a word of caution here: The fact that salmon start their life in resh water means that they are vulnerable not only to fishing (because hey concentrate as they enter the rivers) but also to anything which upsets he fresh water environment. There has to be enough fresh water for them, nd there has to be access to their spawning areas, access for the large almon to go up and the small salmon to come down. It is quite obvious, hen, that diversion of water to other purposes can reduce the capacity of resh water to rear salmon and that obstructions, including the artificial bstructions we call dams, can do a great deal of damage.

The biologists and the engineers are doing their very best to improve he means of getting salmon past these obstructions. They are making some rogress, but so far the techniques have not reached the stage where dams n major salmon rivers are possible without a serious reduction of the almon stocks and the salmon catch. This means that if the community is o make the very best use of its resources, it must take full account of the ontinuing and increasing salmon resource (because it *is* increasing everyhere) and avoid developments which will damage salmon production.

It becomes, in the end, a matter of equating values, and if a salmon shery is destroyed by any development, what is lost both in present roduction and in the very real potential is really a cost to the community

of that development. So we think that salmon and power and other water uses can live together in British Columbia, but mainly by living in different streams. There are still quite a few streams.

I would like to touch on a field which is much more adventurous. I think all of you know that there have been various attempts to increase the production of salmon by artificial means. Everybody has heard of hatcheries, and the words "artificial propagation" and so forth have been very common in the last 50 years. So far these have not been very effective. This is so true that the Department of Fisheries discontinued, two decades ago, a program of operation of hatcheries for sockeye salmon. We can't, however, leave it at that. There is a lot more to artificial propagation of salmon than just hatcheries. We are now learning more about the conditions required for the life and development of salmon, and are devising means of increasing salmon production which seem to be promising.

The basic principle back of all this is that salmon eggs need water, and water of certain kinds with enough oxygen and with enough flow to carry away waste products and so forth. We are beginning to learn now just what they do need at various stages. Recently, in various experiments, it has been demonstrated that production of salmon fry in gravels, with controlled water flows, can be many times the ordinary natural production. I think we can go still farther than that, maybe, and explore still more intensive means. One of the interesting aspects of this problem is that we must take the migratory habits of salmon into account, and only very recently we have learned a good bit about them. We have learned the way in which very young salmon can learn habits of migration very quickly. The old fish culture hatchery methods did not take these problems into account.

This is touching very briefly on a field which I think can be quite important, but it is a field in which it is impossible to predict just what might result. If means can be developed of raising pink and chum fingerlings economically, to the stage where they go to the sea, very great possibilities are opened up. We don't yet feel sure that this can be done, but I certainly feel that there is a reasonable hope. I am optimistic enough to feel that this is something that we must follow up and that there is good chance that we will get something out of it.

Turning to other fisheries, we have the existing sea fisheries that have been touched on: halibut and herring. The halibut fishery passed a peak of exploitation. It declined, apparently, to a large extent from over-fishing. It has been under successful regulation by an international commission, and the decline has been arrested and increase is in progress. The indications are that this increase—this is just my personal guess, nobody has made such an estimate officially as far as I know—that this increase is not likely to provide more than another 40 or 50% of the present yield.

Perhaps herring, as Dr. Shepard suggests, are in the same position. I am more doubtful about herring because I am far more skeptical about what we know about herring than what we know about either salmon or halibut. Herring, like other pelagic fish that swim up in the water, are very difficult to study to the stage at which we know just where the herring populations are at all times. Fishing, the world over, depends on concentrations of fish, and when concentrations don't occur, profitable fishing can't be carried out. Very often, this is what is meant by saying "There are

› fish here", or "no fish there" –concentrations have not been found. If l the fish on the Grand Banks of Newfoundland were spread evenly over at area, the Grand Banks would not be a commercial fishing area. milarly herring can be caught profitably only when concentrated and the me, place and degree of concentrations cannot yet be predicted reliably.

There are new fisheries inshore that are possible. These fisheries epend on increasing demand and on development of methods of processing id marketing. I would like to mention even the humble dogfish which is ie basis for much of the fish-and-chip trade in London, England. We iow from past experience that we could probably catch 20,000 tons, 0,000,000 pounds, of dogfish annually. These will eventually be used. ttempts are being made now to use dogfish for reduction. Some time iey will be used for food.

The potential of shellfish must not be forgotten, especially that of yster farming. This field is being ably explored by the Provincial fisheries uthorities. Its production could be multiplied many times when demand istifies the necessary effort.

I see my time is running out, but there remains perhaps the most omantic part of the whole picture. We are on the north eastern coast of ie world's greatest ocean where there are large stocks of tuna, which our eople already eat, and also very large stocks of other fish which we do not se yet but which constitute important parts of the fishery of the Asiatic ations, particularly Japan. Recently we have been learning quite rapidly bout how this ocean works, how its waters move and their properties iange. The distribution of the tuna and other species has been shown to epend on such oceanographic knowledge, and fisheries have been eveloped by other nations by making use of it. There is a very real ossibility that as this oceanographic knowledge is improved, we can find rge stocks of tuna close enough to use economically, and that we shall be ble to understand and even predict the variations in their occurrence, ir enough ahead to be of use to the industry. As the world's need for fish icreases, other fish will come into use. I don't think that anybody can say ist when, but there are other fish in the area, such as saurics, and which ill some time be used—perhaps not in my lifetime, but I feel sure that if y son lives to a good ripe old age, he will see them used.

Actually, if one looks at the history of fisheries throughout the world, e principal way in which fisheries have expanded has been by discovering id using new species from time to time.

I haven't touched on the technological side because that is a little bit it of my field. I would just like to sum up by saying that in my opinion. e potential is there for large expansion, and we can cash in on this otential only by learning a great deal more than we now know about how manage the fisheries, and only by using that knowledge effectively. The timate future of the industry depends on the increasing world demand id on learning how to catch fish even more efficiently than we now do.

ABUNDANCE, DISTRIBUTION AND COMMERCIAL EXPLOITATION OF THE FISHERIES RESOURCES OF CANADA'S WEST COAST

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Introduction

The development of the fisheries of Canada's west coast has been characterized by increasing exploitation of inshore stocks. Fishing for salmon, herring, halibut and other groundfish, the main contributors to the commercial catch, has been restricted to the waters of the continental shelf, usually within 30 miles of shore. The development of fishing and processing techniques has been such, that if demand were sufficient, almost all inshore stocks could be exploited maximally. Exploitation of the fish stocks of the high seas (e.g. tuna) is still in the exploratory phase and in these fisheries Canada lags far behind some of the other great maritime nations of the Pacific area, notably Japan.

For the inshore stocks, the degree of exploitation varies greatly from species to species and even from population to population within species. The salmons, which spawn in fresh water, are extremely vulnerable to fishing during their migration from the sea. In consequence some stocks (e.g. the sockeye of the Skeena River) have become depleted by the fishery to a point where the annual yield is probably below what it could be had larger numbers of fish been allowed to reproduce. Indeed, with present fishing methods, were it not for rigid restriction of the fishery by government management agencies, many stocks would be faced with virtual extinction. In addition to heavy fishing the salmon stocks face depletion through deterioration of their spawning and fresh-water nursery areas associated with the increasing spread of industry and agriculture throughout the province. An example of those serious effects occurred in the Fraser Canyon in 1913 where as the result of railroad construction activity, tons of rock fell in a narrow part of the canyon, making this point virtually impassable to the Fraser River sockeye run in that year. The result was that the stocks of one of the world's most productive sockeye rivers were reduced to a low level from which they are still recovering. Removal of forest cover, by increasing the rate of run-off and providing poor conditions for incubation of eggs, is endangering some pink, chum and coho salmon stocks.

Other fisheries are at a point where, considering year to year fluctuations imposed by oceanographic and climatic conditions, the present rate of exploitation is yielding close to maximum production. Fisheries on certain of the sockeye runs on the Fraser River fall in this category, whereas the halibut and herring fisheries are fast approaching this point.

Other stocks, for lack of demand at current market prices, are not being fished to their maximum capacity (e.g. the rock sole and butter sole of Hecate Strait) or are taken scarcely at all (e.g. the saury). Still other fisheries are of a sporadic nature, their stocks not being found in abundance in the waters off Canada's coast-line in all years (e.g. the pilchards and the tuna which were last fished in 1947 and 1953, respectively).

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Although many of the species taken in British Columbia are found on other parts of the Pacific coast (e.g. spring salmon which are caught from California to Alaska), in many cases the *individual stocks or populations* of fish are exclusively Canadian and support a completely Canadian fishery (e.g. the British Columbia herring). In other cases, where fishing takes place outside Canada's territorial waters (e.g. the halibut fishery), or where the stocks involved have migration routes passing through Canadian, American and or international waters (e.g. the Fraser River sockeye), Canada competes with the United States for fish. In the two examples cited above (halibut and Fraser River sockeye) international commissions propose fishery regulations aimed at making best use of the resource and at effecting an equitable distribution of the catch. The capture of whales is regulated in accordance with an international whaling treaty, of which Canada is a signatory. However, there is a number of fisheries (e.g. the trawl fisheries of Hecate Strait and the pink salmon fishery of the Puget Sound-Fraser River area) which are not under international control and where adequate regulation of fishing is difficult.

Assessment of the present status of the fish stocks utilized by the fishing industry of British Columbia requires knowledge of the abundance, distribution, rates of utilization and natural reproductive and growth rates of the stocks. Although much has been done by the various research agencies in the province to provide these data, the biological information on the existing stocks is, as yet, far from adequate. In the following pages an attempt has been made to examine each of the major fisheries of the province, with a view to determining how thoroughly the stocks of fish are now being exploited.

It should be recognized that complete accuracy cannot be claimed for all figures, especially those relating to the size of stocks. It has been necessary in many cases to use intelligent approximations in place of well founded facts. For this reason, many of the statements made must be considered as the "best guesses" that can be made from available information rather than as final scientific conclusions.

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Sockeye Salmon—*Oncorhynchus nerka*

The sockeye is the most valued of Pacific salmons. The landed price in recent years has been close to 25 cents per pound, in the round. In the

following pages, the abundance and utilization of the sockeye stocks in each of the major river systems have been discussed separately. This treatment is desirable because each of the fisheries described has its own history and its own problems.

With very rare exceptions, all races of sockeye are reared in a lake for one or more years, and so a river's sockeye production depends in the first instance upon its having suitable lake nurseries. Adult sockeye move upstream in summer or early autumn, to spawn in tributaries or outlets of a lake, or sometimes in the lake itself. In British Columbia, their eggs hatch the following spring and the young remain in the lake usually for one or two years. After going to sea, some return after one full growing season and part of the next (as "jacks" — small fish not taken in any quantity by nets now in use), but most remain $2\frac{1}{2}$ or $3\frac{1}{2}$ growing seasons. Apart from jacks, maturing sockeye average about 7 pounds in weight, but vary from about 3 to 15 pounds.

At sea, sockeye have been found widely dispersed in the Gulf of Alaska, many hundreds of miles offshore, though the movements of Canadian-born fish have not specifically been identified. (In the western Pacific there is an important pelagic fishery by Japan for this and for two other kinds of salmon).

Little ocean tagging of sockeye has been done, but our southern stocks, at least, appear to move inshore and alongshore from the northwest. As with other salmon, "homing" of sockeye to native rivers and native tributaries has been demonstrated to occur with sufficiently high incident to make this a fundamental basis of management policy.

Fraser River Sockeye

History

Exploitation of the Fraser River sockeye stocks on a commercial scale began with the establishment of the first sockeye cannery at New Westminster in 1866 (Rounsefell and Kelez, 1938). On their migration to the spawning grounds of the Fraser, the sockeye pass through both Canadian and United States territorial waters and since the early days of the fishery, they have been exploited by both nations. By the end of the 19th century, the fishery was at a point where, in many years, full use of the stocks was being approached.

The Fraser River stock is divided among some 20 lake systems, about 8 of which are or have been major producers. For almost all runs, the predominant age at maturity is 4 years, and in many lakes one "cycle" or line, out of the four tends to exceed all the rest. In individual spawning areas, the dominant line has been as much as 100 or 1,000 times as abundant as one or more of the other lines. The fact that no lake has ever had more than one really large dominant cycle (though sometimes one of the others is moderately numerous) suggests that big year stocks may actively suppress the subsequent off-year stocks (Ricker, 1950). Prior to 1917, for as far back as historical records exist, the stocks of all the major upriver tributaries had dominant years in the 1901 line. Thus, the catches of 1897, 1901, 1905, 1909 and 1913 greatly exceeded those of the intervening years. Indeed, the catches in these big years provided over 60% of the total catch made in the 20 years prior to 1917.

During the 20-year period prior to 1917, the Fraser proved to be one

of the greatest sockeye producing rivers of the world, providing an average annual catch of well over 700,000 cases (see accompanying figure). During this time the 1901 and 1902 cycles both maintained their abundance and their catch but by 1915-1916 the catches from the 1903 and 1904 lines had decreased to a quarter or less of their maximum, possibly because these "off" years were less capable of sustaining an intensive fishery than the dominant one.

However, due to rock dumping at several points and destructive slides which accompanied railway construction in 1913 and 1914, the major part of the escapements of the "big" year 1913 and its successor were prevented from reaching their spawning grounds. The stocks produced by these spawning (which returned in 1917 and 1918) were very badly reduced, and the 1901 cycle fell off seriously again in 1921. The various rock dumps were removed or remedied in time for the 1915 runs, but at Hell's Gate, particularly, it was impossible to restore the original channel completely, and sockeye were observed to be held up there intermittently in succeeding years. These reverses reduced the 1901 cycle to a status no greater than its fellows in the overall picture, though it retained superiority, at a low level, in a number of nursery areas. During the early 1920's the average pack was only 16% of that of the 20 year period prior to 1917.

The upriver stocks remained at a low level until the late 1920's, when the late Shuswap run, one of the major contributors to the Fraser catch, began to show signs of increase. Since then all of the old major producing areas have again contributed significantly to the annual pack, and the average annual catch (1951-1954) has risen from the low of 15% to over 50% of the old level. The dominant runs of the various areas no longer occur in the same year, with the result that the catches are spread more evenly over each 4 year period. However, there is still some tendency for a general 4 year periodicity in the Fraser, because the Adams River run, with its dominant cycle occuring in the 1902-1954 line, is by far the most abundant of all the present Fraser runs.

In the following table, the average annual catches (in thousands of 48 lb. cases) for 4 year periods since 1895 are listed. In recent years, the average number of sockeye required per case has been approximately 10 (9.99).

Year	U.S.A.	Canada	Total
1895-98	176	467	643
1899-1902	543	483	1026
1903-06	327	324	652
1907-10	403	218	621
1911-14	580	275	855
1915-18	153	73	226
1919-22	70	45	114
1923-26	68	48	116
1927-30	156	64	220
1931-34	162	75	237
1935-38*	77	134	211
1939-42	119	182	301
1943-46	97	132	230
1947-50	74	63	137

Year	U.S.A.	Canada	Total
1951-54	228	228	456
1951	118	134	253
1952	115	116	230
1953	178	176	354
1954	501	487	988

* Figures to 1936 include a few thousand cases of sockeye caught in Johnstone Strait, part of which are bound for the Fraser River. Figures after 1936 include sockeye taken only in International Pacific Salmon Fisheries Commission Convention waters.

Present Status

In 1937, the International Pacific Salmon Fisheries Commission was created by a treaty between Canada and the United States. The Commission's first job was to determine the cause of the decline in the Fraser River sockeye population since 1916 and to develop practical methods for restoring the runs to the "maximum sustaining size" (Royal, 1953). During the eight years that followed formation of the Commission, extensive biological and engineering studies were made of the Hell's Gate obstruction (Ann. Rept. Int. Pac. Salmon Fish. Comm., 1937-1954; Thompson, 1945; Jackson, 1950, etc.). Reports of delays and mortality at this point had persisted through the 1920's and 1930's. The Commission's research indicated that substantial delays and mortality occurred at certain water levels and that in some cases, delay at the slide decreased the reproductive capacity of sockeye that did manage to reach the spawning grounds. Under these circumstances, the Gate had a varying effect on the upstream passage of the salmon from year to year and also on different runs in the same year. The differential effects have been suggested as the reason for the failure of certain runs to revive after the 1913-1914 disaster and for the successful resurgence of other runs (e.g. for the revival of the late-running Adams River run). After a year of particularly bad obstructions (1941), it was decided that immediate action was needed. A "clean-out" was rejected as inadequate and instead, new style vertical-slot fishways were designed and finally installed in 1945 and 1946. These fishways at once eliminated the obstructive effects of the Gate, permitting easy passage of the sockeye at all water levels.

Similar structures were later installed at the Bridge River rapids of the Fraser and on the Chilcotin River to eliminate delay and mortality at these points.

In addition to easing the passage of the migrating sockeye, to permit the fastest possible restoration of the upriver runs, the Commission initiated a series of early-season closures as soon as it was given responsibility for recommending fishing regulations (in 1946). These lasted 5 years and provided partial-to complete protection for the depleted upriver runs. The success of the Commission's policies may be seen in the fact that nearly all important areas now have spawning stocks numbered in at least the middle hundred thousands, in at least one cycle.

The most important area at present is the Shuswap Lake system where the late run of fish (spawning primarily in the Adams River) has been restored to its former levels of abundance. The Chilko Lake stock, now the second most important on the Fraser and one which survived the effects of the Hell's Gate obstruction better than the other upriver runs, is believed to have approached capacity production in the early 1940's and

from then until 1954 two lines have been producing a high level. The Stuart system, Fraser-Francois district and Quesnel areas have all shown good increases in the last decade and promise more for the future. However, the distribution of spawners is still not ideal: some runs are not well timed in relation to temperatures on the spawning grounds; and a number of formerly outstanding spawning streams are still very poorly seeded. These include the Driftwood River (Takla Lake), Nadina River (Francois Lake), the lower part of the Horsefly River (Quesnel Lake), Upper Adams River (Adams Lake), the Anstey, Eagle and Salmon Rivers (Shuswap Lake), Gates Creek, and Portage Creek (Seton-Anderson system). Most or perhaps all of these must be restored as major spawning areas before advantage can be taken of the full productive potential of the associated lakes. At Adams Lake a new run has just been started by transplantation where the pre-1913 stocks had been exterminated in all four lines.

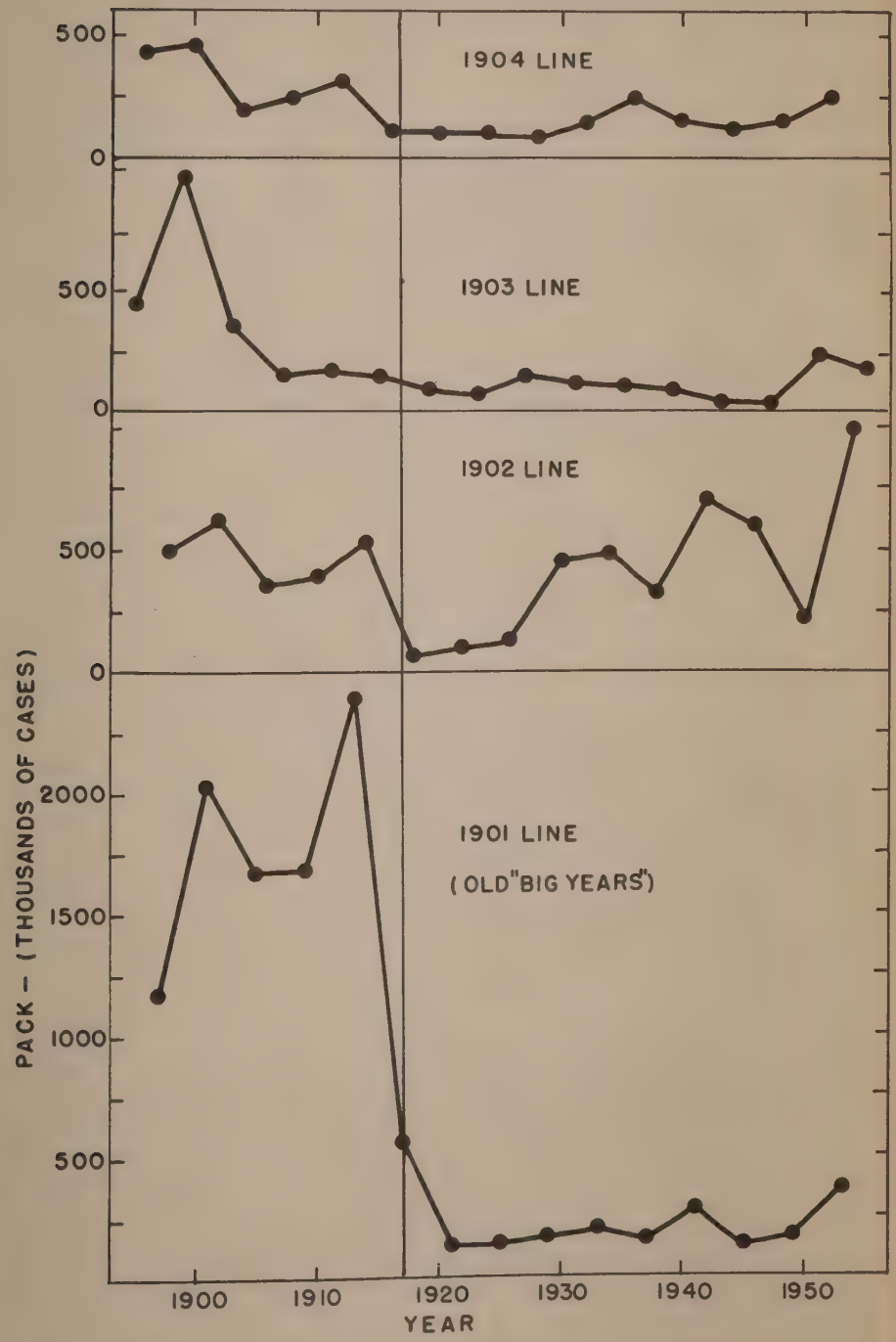
At present about 20% of the annual sockeye run escapes to the spawning grounds. This percentage is maintained only by careful regulation of the fishery; the fishing effort is, at present, so intense that almost every sockeye moving toward the spawning ground could be caught by the fishery if no regulatory measures were taken. When the Shuswap runs have been abundant, regulations have permitted an increased take so that the escapement to this area in these years has been porportionately less (around 13%).

The present catch level (as indicated by the 1951-1954 average) is in the vicinity of 50% of that existing just before the disastrous slides of 1913-1914. The catch in that early era has generally been considered as the maximum that could be sustained by the stock as a whole. There are indications, however, that the runs in some of the big years prior to 1914 may have been underexploited and that actually the maximum sustainable yield of the Fraser stocks may be even higher than the huge catches of the pre-1914 period. Ricker (1950) points out that in some big years (e.g. 1901 and 1905), the processing facilities were, for periods, taxed beyond capacity, forcing the canneries to impose catch quotas on the fishermen. As a result there were reports of large numbers of fish being wasted and of fishermen strictly limiting their efforts by using less gear or fishing for shorter periods (Babcock, 1902-1914). Observations on the size of the spawning escapements, also reported by Babcock, indicate that the major producing tributaries of the Fraser were filled with fish. Although these reports are largely subjective they do suggest that the number of fish escaping the fishery was greater than the 13-20% of the total run that is estimated to be the annual escapement in recent years. If so, then the present production of the Fraser may be considerably less than half of the ultimate potential of the system.

In addition to providing adequate escapements, the Commission's regulations are also aimed at accomplishing as nearly as possible, a 50-50 split in the catch between Canadian and American fishermen. This latter aim has been achieved with remarkable precision. In the eight-year period from 1947 to 1954, the division of the catch between Canada and the United States has been very close to 50-50, with the Canadian fleet taking an average of about 50.8% of the catch and the Americans 49.2%.

While the attainment of maximum production on the Fraser remains a feasible and exciting prospect, the urgent demand for hydroelectric

Fraser River sockeye packs arranged by lines or "cycles". Vertical line at 1917 indicates the year of the first effects of the canyon obstructions of 1913.



power in B.C. poses serious immediate problems. A general survey, being conducted by the Federal Government, outlines a possible program for power development on the Fraser. The full program embodies a series of 4 dams on the main stem of the Fraser and 6 dams (suggested sites) on the Thompson River with a diversion of 10-million-acre feet of storage water from the Columbia through a bypass not yet chosen. Supplementary storage has been considered on a number of the Fraser lakes including several of the major sockeye-producing lakes of the system (e.g., Shuswap, Quesnel and Stuart.) Whether or not any or all of the program will be implemented in the near future is a matter of conjecture. However, the possible effects of the full development on the sockeye has been reviewed by the Department of Fisheries (Anon., 1956) and can be summarized briefly as follows:

The development would:

(1) interfere with the upstream migration of adult salmon to the spawning areas in the Fraser and Thompson Rivers, and with the downstream movement of the young from the spawning areas;

(2) interfere with the spawning grounds in Stuart, Thompson, South Thompson, Little Adams, Seymour, Eagle and Horsefly Rivers and possibly on the Middle Shuswap and Tachie Rivers;

(3) interfere with the unique upstream fry migration in the South Thompson River;

(4) possibly alter the ecological conditions through the development of storage reservoirs, particularly on Shuswap, Kamloops and Stuart Lakes;

(5) quite possibly disturb the important normal temperature regime of the Fraser, Thompson, South Thompson, Adams, Seymour, Eagle, Shuswap, Quesnel and Stuart Rivers to the detriment of the propagation of the species frequenting these rivers.

It is not impossible to design structures which will move the runs of adult fish above the dams in question, especially since these are of comparatively low head, varying from 35 to 100 feet. The difficulty will arise in accommodating the extremely large runs without serious delay. In recent years an increasing body of evidence has been built up, indicating that delay during migration reduces the ability of sockeye to spawn successfully (e.g. Ann. Repts. Int. Pac. Salmon Comm., and Godfrey *et al,* 1954). Delays in migration which could be caused by a series of dams despite the best available fish facilities might conceivably add 10 to 14 days to the migration time of salmon proceeding to the Upper Fraser River system and 16 to 26 days to the time of those proceeding up the Thompson.

To date, research aimed at devising means of passing downstream migrants through power dams has met with only limited success. (Andrew *et al,* 1955). Unless adequate methods are developed, it is estimated that 80% of the Thompson River migrants and 48% of the Upper Fraser migrants would be killed in passage over the sluice-ways and through the turbines of the dams.

Until more information is obtained it is impossible to assess the effects which power development might have on the ecological conditions of the various lake nursery areas and on the temperature regimes of the important spawning streams. However, it is difficult to see how these changes would

benefit the sockeye and it must be concluded that these efforts would probably further the destruction of the stocks.

Unless research can devise revolutionary methods of passing both juvenile and adult fish, with little or no damage to the fish or disruption of the normal migratory pattern, construction of extensive hydro-power dams would undoubtedly cause depletion of the sockeye stocks. To a point, the partial development of the power plan might still permit a limited fishery on the Fraser stocks, but full development of the program would probably spell the end of a great primary industry - the Fraser River sockeye fishery.

Skeena River Sockeye

History

Unlike those of the Fraser system, which mature predominantly at 4 years of age, the vast majority of the Skeena River sockeye mature at both 4 and 5 years of age. Over the past 40 years the 4's and 5's have been represented in approximately equal numbers, although in any one year one age class may be greatly in excess of the other. Because of the presence of two major age classes, the phenomenon of 4 year dominance with its associated "big" year occurring on the Fraser has been lacking on the Skeena. However, the 5 year old fish of the Skeena had a series of big broods between 1914 and 1924, while a series of large 4 year old broods occurred in the period 1936-1952.

The 5 year average packs are shown below in cases (one 48 lb. case = about 75 lb. raw fish = about 12 sockeye).

Years	Av. catch (thousands of cases)	Adjusted No. of boats	Years	Catch (thousands of cases)
1906-10	122	980	1951	62
1911-15	105	1050	1952	115
1916-20	105	1130	1953	65
1921-25	99	1190	1954	50
1926-30	82	1950		
1931-35	56	1940		
1936-40	71	1080		
1941-45	69	880		
1946-50	60	(820)		

The catches of 1952 and 1954 would have been considerably higher except for a strike (1952) and a closure (1954) near the peaks of the runs.

The pack was at its highest in the early 1900's. In the late 1920's and early 1930's it declined rapidly to between 50 and 60% of the early peak level. Although there has been a tendency for a slight increase in the last few years, the catch has remained at this general level ever since.

Milne (1955) has assembled the statistics on the number of boats fishing on the Skeena and their relative efficiency. The evidence suggests that overfishing was an important contributing reason for the decline. The amount of effort expended in fishing (expressed as an adjusted number of boats fishing, in the table above) increased up to the late 1920's, remained high until 1935, then gradually decreased until 1941 when the war-time suspension of fishing by Japanese Canadians caused a sudden drop.

Fishing effort remained at this reduced level throughout the war

Measures of effort for the post-war period are not readily comparable to the earlier figures because increasing efficiency of gear and mobility of the fleet in recent years make such comparisons difficult. Taking into account the fact that effects of any one year's fishing on the stock would not be detected until the progeny of that stock returned as adult migrants four or five years later, the period of high effort (1915-1935) was one which produced declining catches, while the catch data suggest that recently the stocks have been on the upswing.

There is evidence that some of the spawning grounds of the important Babine watershed may have been damaged by extensive forest fires in 1921-22. These fires promoted a more rapid run off during flood times and reduced the minimum flow in the low water season. It is likely that these conditions also contributed to the decline of the stock.

Spawning ground surveys indicate that the run to the largest lake in the system, Babine (174 sq. mi.), comprises about 70% of the total escapement to the watershed (Brett, 1952). The remainder of the run is spread between some 12 lakes, having a combined area of about 90 sq. miles.

Present Status

In recent years average exploitation has been about 50%, with the commercial fishery taking around 43% of the stock, and the Indian fishery taking about 7%.

As the Babine run provides the great majority of the fish taken in the fishery, management of the Skeena stocks has involved mainly regulation of fishing to permit adequate escapements to the Babine area. The most immediate management problem is a serious depletion in spawning stocks caused by a disastrous slide in the Babine River in 1951 (Godfrey *et al.* 1954). Before it was removed in the winter of 1952-53 this slide prevented the upstream passage of around ⅔ of the Babine spawning runs of 1951 and 1952. In addition to the destruction at the slide, many of the fish that did manage to pass the slide had been injured and delayed and did not spawn effectively. By institution of closed periods in 1955, 1956 and possibly in 1957 to protect the returning progeny of the slide-affected runs, restoration of these runs will be accelerated.

In the long term, sockeye production at Babine Lake has not approached that occurring in other major producing lakes of British Columbia. While lakes such as Shuswap, Chilko and Fraser in the Fraser River drainage provide catches to the fishery averaging some 15,000 fish per sq. mile of lake surface area and Owikeno Lake at Rivers Inlet supports a fishery taking about 34,000 fish per sq. mile, Babine Lake provides an average annual catch of only 3,300 sockeye per sq. mile. Comparison of the general limnological characteristics of Babine with those of the other big producing lakes does not bring to light any factors which could be blamed for its low sockeye productivity. However, recent studies have suggested that poor distribution of spawning facilities may prevent young sockeye from utilizing the lake's food resources fully (Johnson, 1956). If such a condition is shown to be restricting the yield from Babine, it is possible that re distribution of the spawners through regulation of escapement from the fishery would help to overcome the present limitation.

As most of the stocks utilizing other areas on the Skeena tend to move through the fishery at the same time as the predominant Babine run it may

be difficult to formulate specific fishing regulations to favour any particular stock other than that of Babine. However, steps have been taken to increase the run to Morice Lake, the second largest producer on the Skeena, by construction of a fishway at Moricetown Falls, a point of difficult passage for the Morice sockeye.

A number of power and logging development plans exist for the Skeena. In some cases these involve destruction of present spawning grounds, or the obstruction of migratory routes. At this stage, it is difficult to make useful predictions on the effects of such developments on Skeena sockeye stocks, except that it is assured that unless each development is fully compensated for by the provision of spawning, nursery, or migratory facilities equivalent to those now present, serious reduction of the stocks will follow.

Although there will be some low packs in years when the runs depend heavily on progeny from runs spawning during the slide period (e.g. in 1956 and 1959), there is reason to believe that the unaffected Skeena stocks will increase in abundance over the next few years.

Nass River Sockeye

History

Four major age classes occur in the Nass River sockeye stocks, 4 and 5-year-old fish with a 1-year freshwater phase, and 5- and 6-year-old fish that spend two years as young in the lakes before they migrate seawards. The proportions of these age classes vary considerably from year to year, although almost invariably the 5-year fish with two years in the lake predominate.

Annual packs by 5-year averages, in 48-lb. cases, are shown below (1 48-lb. case = 75 lb. raw fish = about 10 sockeye):

Years	Av. catch (thousands of cases)	Years	Av. catch (thousands of cases)	Years	Catch (thousands of cases)
1911-1915	26	1931-1935	18	1951	24
1916-1920	24	1936-1940	21	1952	29
1921-1925	22	1941-1945	17	1953	18
1926-1930	15	1946-1950	15	1954	10

At least until recent years, the history of the sockeye fishing effort on the Nass has probably paralleled that of the Skeena, the period of most intensive fishing being from 1915 to 1935. Formerly Nass catches were packed in canneries located near the river mouth, but more recently they have been taken to the Prince Rupert area on the Skeena River and canned there. With the Nass fishery, the decrease from the early peak production to the low packs of 1926-30 probably indicates overfishing, and as with the Skeena this occurred during the period 1915-1925. After 1941 fishing effort was reduced because of circumstances related to the war, following which respite there were increased catches in 1951 and 1952.

The distribution of the spawning escapement in the Nass watershed is not very well known, but the only important nursery lakes are the Medziadin and the Bowser. Falls in the Medziadin River which flows out of Medziadin Lake used to constitute an obstacle to adult migrants at times of low water, but the construction of a simple fishway in 1913 alleviated

that situation. No other serious obstacles have been reported on the Nass, nor have any catastrophic phenomena occurred within the known history of the area.

Present Status

The rate of utilization of the Nass stocks cannot be estimated accurately because of the remoteness of the spawning areas and the resultant difficulty of knowing escapements. The similarity of the history of the fishery with that of the Skeena River might suggest a similar rate of utilization (50%+).

The Nass nursery lakes have a combined area of about 45 square miles. At the present time they provided an average annual catch of about 4,600 sockeye per sq. mile. This is considerably lower than that of the best Fraser River lakes, but somewhat greater than that of Babine Lake on the Skeena. The reason for the relatively low productivity cannot be ascertained at present.

Proposals exist for the utilization of the Nass waters for industrial purposes, but since it is not known how they will affect migration routes or nursery areas, no useful predictions of resulting changes to stocks can be given.

Rivers Inlet Sockeye

History

As on the Skeena River, at Rivers Inlet there are two major age classes of adult sockeye (4- and 5-year-old fish). Rivers Inlet has also experienced a series of large broods of 5-year-old fish occurring at 5-year intervals early in the 1910-1954 period of recorded age class composition, and a series of large 4-year-old broods occurring at 4-year intervals, in the latter part of that period.

The annual packs by 5-year averages, in 48-lb. cases, are shown below:

Years	Av. catch (Thousands of cases)	Years	Av. catch (Thousands of cases)	Year	Catch (Thousands of cases)
*1907-1910	74	1931-1935	88	1951	103
1911-1915	97	1936-1940	67	1952	84
1916-1920	67	1941-1945	69	1953	133
1921-1925	94	1946-1950	87	1954	51
1926-1930	76				

* Four-year average.

The history of the development of the fishery and of changes in the fishing efforts at Rivers Inlet has been similar to that of the Skeena. However, the prolonged decline in catch which was experienced in the Skeena River during 1920-1935 did not occur at Rivers Inlet. Apart from annual variation, sockeye catches in this system have remained relatively constant during the past 40-odd years.

There is only a single nursery lake (Owikeno) for young sockeye. In the past this lake has supported a sockeye stock which, although probably smaller than the total Skeena stock, has provided catches of equal magnitude. The average yield in 1951-54 was 34,000 fish per square mile of lake nursery area. The spawning beds at Rivers Inlet appear to be more than adequate for the number of sockeye produced here, so that the capacity of this lake to feed young sockeye is considered to be the principal factor limiting further production. Among the features of Owikeno Lake that

probably contribute to its relatively high sockeye productivity is that it has extensive spawning streams flowing into the uppper part of the lake. When the fry enter the lake, they are probably quickly distributed over the lake and, unlike at Babine Lake on the Skeena, use the available food supplies to best advantage.

Present Status

Utilization of the returning adults at Rivers Inlet is estimated at about 65 per cent, somewhat heavier than that occurring on the Skeena, but below that existing on the Fraser.

Because of its small size and isolated location, prospects for important industrialization of the Owikeno drainage are not immediate. It is likely that under the present rates of exploitation and in the absence of industrial development, the stocks will maintain themselves for some time to come.

Smith Inlet Sockeye

History

At Smith Inlet more than 95% of the adult sockeye taken in the fishery are 4- and 5-year old fish. The proportion of two age classes varies from year to year.

The annual packs, by 5-year averages, in 48-lb. cases, have been as follows:

Years	Av. catch (thousands of cases)	Year	Catch (thousands of cases)
1926-1930	23	1951	49
1931-1935	24	1952	35
1936-1940	23	1953	30
1941-1945	14	1954	19
1946-1950	23		

There has been no prolonged decline or increase in the Smith Inlet sockeye catches since the fishery was first developed. A slump did occur during 1940-1945, which may have resulted partly from lowered fishing effort during the war. The recent catches have averaged as high, or even slightly higher than these in the past.

The only significant sockeye nursery lake at Smith Inlet is Long Lake, with an area of about 7.5 sq. miles. There are two important spawning streams.

Present Status

Long Lake at Smith Inlet is the most efficient known producer of sockeye in British Columbia—even more efficient than Owikeno. The 1951-1954 average catch was 335,000 sockeye, or 44,000 per square mile of lake.

As at Owikeno Lake the fry enter the upper part of the lake and hence have a good chance for uniform distribution throughout the lake, at an early age. Because the Smith Inlet sockeye yield is so great—44,000 fish per square mile of lake—we estimate that the rate of utilization is high—about 75%.

No major adverse changes in the natural environment are likely to occur in the near future. Thus, the present yield of sockeye will probably be maintained for some years to come.

Sockeye of Other Areas

History

A fairly large number of additional lakes situated along the mainland coast and on Vancouver Island contain sockeye populations. Catches in recent years, were in thousands of cases:

1950	40	1953	73
1951	44	1954	43
1952	51		

The 1951-54 average was about 50,000 cases. The rate of exploitation is estimated rather arbitrarily at 55%.

None of these areas has suffered important changes, and their catch has probably been about the present level for some time.

Present Status

Since many of the areas under discussion are so scattered, reliable estimates of spawning runs has often not been possible. With increased accessibility of and attention to the runs, a more efficient ratio of catch to escapement—either greater or less—may become possible in some places.

Fishways recently constructed on the Sproat, Stamp and Nimpkish Rivers are expected to increase sockeye production from Sproat, Great Central and Nimpkish Lakes. A few other runs may benefit from future constructions.

Among the largest lakes in the group under consideration are several that drain to the west coast of Vancouver Island: Kennedy, Henderson, Sproat, Great Central and Nitinat, which have a combined area of about 400 square miles and today give a catch of about 135,000 sockeye on the average, or only 340 per square mile. The waters of this region are very poor in dissolved nutrients, and the very heavy rainfall subjects spawning streams to violent freshets. However it may prove that a reasonable annual expenditure could ameliorate one or other of these handicaps and greatly increase production.

On the other hand, a hydro-electric development has already been projected that involves the Alberni lakes (Sproat-Great Central), which in its present form could scarcely fail to limit salmon production in at least one of these lakes.

Pink Salmon—*Oncorhynchus gorbuscha*

History

Pink salmon are today the most abundant salmon in British Columbia. They spawn in more than 1,000 streams, situated both on the mainland and on many of the coastal islands. The only major area which does not contribute significantly to the natural propagation of the stock comprises portions of southern and western Vancouver Island.

Some pink salmon spawning grounds in the Fraser and Skeena watersheds are situated several hundred miles upstream from the river mouths. Much spawning, however, takes place relatively close to salt water, at times even within the range of tidal influence. The fry travel to the ocean as soon as they emerge from the gravel beds and hence are probably not dependent on freshwater food supplies to any extent. Maturity is reached at an age of two years, the length of the life cycle being invariable to the best of our present knowledge. Pinks can be taken well out to sea, away from the continental shelf, but present results suggest that they do not travel as far as chum and sockeye salmon.

Within living memory and probably before, a special situation has existed in two important areas, (a) the southern mainland region comprising Howe Sound, the Fraser River and Puget Sound (Washington) and (b) the Queen Charlotte Islands area. In both these regions, the majority of the spawning streams support pink salmon in only one year out of every two. This alteration of "good" and "off" years can exist because of the unvarying two-year life cycle; two separate stocks are required for runs to occur every year. In the lower mainland the even-numbered year stocks are almost non-existent, while pink salmon are lacking or very scarce in most of the Queen Charlotte streams in the *odd-numbered* years. In recent years these two regions have provided approximately 30% of British Columbia's average annual catch.

Although pink salmon showed some commercial importance prior to the war of 1914-18, intensive exploitation of the species by British Columbia fishermen dates from that period. However, as early as 1907 considerable catches were being made by Washington fishermen from stocks which undoubtedly spawned to a large extent in British Columbia waters. Since 1918 pink salmon fishing has been prosecuted in all the main geographic regions of the British Columbia coast and, with a few exceptions due to economic conditions or to the peculiarities of a particular area, exploitation has been complete within the limits imposed by regulations adopted for conservational reasons. A review of trends up to 1947 is given by Hoar (1951). The catches since 1920 are shown below. The average weight of a pink salmon is about 4.5 pounds.

Period	Average catch (millions of fish)	Year	Catch (millions of fish)
1920-23	8.2	1950	8.0
1924-27	9.3	1951	13.0
1928-31	12.3	1952	11.2
1932-35	7.5	1953	11.1
1936-39	9.6	1954	5.4
1940-43	5.8	1955	11.0
1944-47	9.2		
1948-51	10.0		
1952-55	9.7		

Since 1917 the annual British Columbia catch has fluctuated noticeably but the long-term trend has been remarkably stable. Total stocks were probably slightly greater before and during the 1920's than in subsequent periods, but there seems to have been no continued decline since that time.

However, since the commercial fishery began, two stocks have been reduced considerably below their former levels; those of the Skeena River area and of the lower mainland region.

On the Skeena, as in other northern British Columbia areas, a marked slump in pink salmon catches occurred in 1932, apparently as a result of exceptional droughts in 1930. In most places, the former level of catch was restored, but in the Skeena area this slump and a somewhat similar depression which occurred in the "odd-year" line a few years earlier, have not been followed by subsequent restorations of catch-level (Milne, 1955). Annual catches which in the 1920's averaged near 2,500,000 fish have averaged scarcely half this quantity since 1930.

In the early years of the twentieth century, the pink stocks of the lower mainland area were probably much larger than those existing today. These stocks, which are exploited by both Canadians and Americans, supported a fishery taking in excess of 15,000,000 fish per odd-numbered year from 1911 to 1919 while in recent years (1947 to 1953) the combined Canadian and United States catch has been in the vicinity of only half that figure.

Although the largest combined catch (more than 22,000,000 fish) was made in 1917, the runs prior to that date were not exploited in proportion to their abundance. At that, these stocks had already suffered a major disaster at Hell's Gate in 1913. The upriver escapements prior to 1913 were reported to run into the millions, and were wiped out in that year. Rounsefell and Kelez (1938) have calculated an index of pink salmon abundance from catches of traps north of Deception Pass in Puget Sound, which shows an abrupt decrease between 1913 and later years, suggesting a decrease in *stock* by about 75%. The traps in question were situated so that they probably measure *Fraser* fish almost exclusively (not those of Puget Sound, Howe Sound, etc.), but the stock of the whole region probably decreased by at least 60% at that time. No recovery of the pink runs to the upper Fraser was observed until after fishways were constructed at Hell's Gate in 1945.

In common with other salmon fisheries, the history of pink salmon exploitation has been marked by the introduction from time to time of larger vessels with longer range, new or improved aids to navigation and communication, and more efficient fishing gear. Due to competition for the limited (although large) quantities of fish available, there has been a trend towards catching the fish at an earlier stage in their migration, at points more remote from the spawning streams.

Present Status

Tagging experiments (e.g. DeLacy and Neave, 1947) and comparisons of catches and spawning escapements in certain areas have indicated that present exploitation of the runs amounts to about 50%. The rate may be somewhat higher or lower in certain areas and was probably lower (perhaps 40%) prior to 1945. The recent increase in rate of utilization has not resulted in any apparent increase in yield. Hence the fishery is now as intensive or even slightly more intensive than that required to provide a maximum sustained yield.

Present management policy seeks to prevent depletion of stocks in the face of a continuous increase in fishing pressure. Provision of adequate spawning stocks in the lower mainland area is complicated by the fact that a large part of the stock is fished by both Canadian and American fleets. In the absence of an international regulatory group, similar to the International Pacific Salmon Fisheries Commission, (which proposes regulations for the joint Canadian-American sockeye fishery) adequate control of the increasingly intensive pink fishery cannot be maintained.

In addition to the increase in fishing pressure, other agencies are at work to depress the pink stocks. In recent times reduction of forest cover has threatened pink populations in some areas. In 1955, fast run-offs following heavy rains almost destroyed the seeding of many streams in the lower Fraser region. The construction of large power dams would jeopardize certain pink stocks, notably those of the upper Fraser, which are only now recovered from the disastrous Hell's Gate slides of 1913.

However, since pink salmon spawn to a large extent in the lower portions of the larger watersheds and also in many small coastal streams, which do not offer attractive prospects for hydro-electric development at the present time, the construction of dams would be unlikely to have such drastic and widespread detrimental effects for the pinks as they might for sockeye.

To counterbalance these deleterious factors there is a number of promising developments in the management of the stocks. Research to determine the timing of runs to important individual streams is being carried out (most recently on the Skeena) to provide knowledge for more precise regulation of escapements. In recent years considerable sums have been spent to open new spawning areas by fishways surmounting natural obstructions. The success of the Hells' Gate installation (opened in 1945) is an encouraging sign that fishways elsewhere (e.g. on the Bulkley River in the Skeena drainage) may aid in increasing pink stocks. Improvement of freshwater survival through control of water flow, removal of predators, improvement of spawning beds and by artificial propagation have all been attempted on an experimental basis and show promise for future application.

Chum Salmon—*Oncorhynchus keta*

History

Chum salmon resemble pink salmon in that there is only a very short fresh-water life for the fry, during which they feed little or not at all. This species is larger than the pink (average 12 lb.) and matures at 3, 4 or 5 years of age as a rule. In the ocean it goes far out to sea. In British Columbia most chums spawn in short coastal streams. There are not and apparently never were appreciable spawning stocks above the Fraser Canyon. In the Skeena they rarely ascend to Babine Lake or to Moricetown Falls. However in the Yukon River they enter Canada and proceed as far as Teslin Lake.

The chum salmon fishery in British Columbia became intensive at about the same time as the pink salmon fishery, which it resembles in many ways. Chums are exploited in all the coastal areas of the province. In the last few years about 55% of the catch has been made by purse-seines and 45% by gill nets. As compared with pink salmon, a much larger percentage of the catch has been utilized in ways other than canning—most of the catch is now marketed fresh or frozen, and at times smoked or dry-salted. The more varied disposal of the product makes estimates of annual catches for earlier years somewhat less reliable than those for pink salmon. Estimated average catches for 5 year periods since 1920 and the annual catches for 1950-55 are listed below.

Period	No. of fish (millions)	Year	No. of fish (millions)
1920-23	2.6	1950	8.6
1924-27	6.4	1951	6.3
1928-31	5.2	1952	2.5
1932-35	4.2	1953	4.7
1936-39	4.5	1954	5.9
1940-43	5.2	1955	1.5
1944-47	4.4		
1948-51	5.9		
1952-55	3.6		

The distribution of catches for recent years indicates that the species is caught mainly along the central coast and in Johnstone Strait. The United States Puget Sound fishery takes more than Canada does of the stock in the region of the Washington-British Columbia boundary. The situation here is similar to that of the pink salmon, except that there is much more chum spawning than pink spawning in Puget Sound rivers.

Considerable fluctuations in annual catches have been witnessed since 1920. Catches to 1947 were graphed and studied by Hoar (1951) who observed 3 or 4 periods of low catch, the first in the early 1920's. He was unable to decide whether these reflected mainly poor supplies or poor demand, but believed that large fluctuations in abundance had occurred. Although there has been no *long-term* trend downward or upward, marked weaknesses in certain recent years (beginning in 1944) indicate that there has been some reduction in the average abundance of fish since the earlier years of the fishery. The low catch of 1952, however, was due in large part to a prolonged strike in that year. The 1955 catch and stock were low everywhere, as was the case with the sockeye. These two species apparently wander farthest out to sea and have similar length of life, so an exceptionally unfavourable ocean environment at some time during the period of 1953-55 is suggested.

Local areas in which reduced chum salmon catches and/or escapements have appeared within the last dozen years have included Vancouver Island and the Queen Charlotte Islands. In the former area, probable causes include: (1) severe flooding of spawning streams in certain years, (2) intensified fishing of stocks which make long inshore migrations through Johnstone Strait and the Strait of Georgia, (3) changes in stream flow pattern produced by deforestation in the eastern and southern sections of Vancouver Island. On the west coast of Vancouver Island and in the Queen Charlottes past difficulties in the enforcement of closed fishing periods and areas have apparently contributed to a lowering of population levels.

Present Status

As far as known, the rate of utilization of chum salmon, is similar to that of pink salmon: recent tagging in Johnstone Strait (Chatwin, 1953) indicated a rate of exploitation of 50 to 52%. For the whole chum fishing area a rate of about 55% is estimated.

Chum salmon are sufficiently similar to pinks in their distribution, habits and in the length of the freshwater period of the life-cycle to respond to the same favourable or adverse influences. The comments made under pink salmon in general apply also to the present species. The more variable total length of the life-cycle reduces the danger of eliminating a local population indefinitely through a catastrophe which affects only a single season's escapement. Also, the effect on the fishable stock of improved, or worsened conditions is deferred for a longer period.

Since chums make little use of the upper parts of our longer rivers, any construction of main-stem dams on these watersheds would have little effect on this species. An exception is the Yukon River, where chums would be affected by proposed diversions but these chums do not contribute to the Canadian commercial fishery.

The chum's failure to ascend the Fraser Canyon, even in early days,

means that it will probably not become established in the upper part of that river in the same way as the pinks.

Opportunities and methods for spawning-ground management will frequently be similar for both pinks and chums. However, the fact that the two species are so similar in their requirements is likely to lead, under intensified management, to a form of "competition" between them. In considering the maximum output of fish which can be obtained from the use of a given freshwater area, a choice may have to be made as to which species, or what proportion of each, is to be promoted. Under these circumstances pinks would generally be favoured as being frequently more desirable and because quicker results could be expected from management procedures.

Coho Salmon—*Oncorhynchus kisutch*

History

Coho salmon mature predominantly in their 3rd year, and spend one year in fresh water—usually in a river or creek. They ascend both large rivers and small creeks, penetrating to very small tributaries for spawning. About 1,000 streams have coho stocks; in contrast to spring salmon (see next section), the best 10% probably have less than half the total. They are absent from the Fraser River above Lillooet, though present in the Thompson drainage. In the sea they apparently occur, for the most part, fairly close to shore, though occasional individuals have been taken in high seas exploration. Fish tagged off our coast have nearly all been retaken in our waters or in closely neighbouring parts of Alaska and Puget Sound: migrations of more than 300 miles are exceptional.

Fishing is mostly by trolling offshore, by seines and by gill nets. Information on the catches of coho salmon is similar to that mentioned for spring salmon, with the following differences: The proportion caught by gill nets is smaller and more are taken by purse seines. The proportion taken by trollers has always been large, and in recent years has amounted to approximately ⅔ of the total catch. Recent catches are among the largest in the history of the fishery. Catches for the last decade are shown below, in thousands of pounds landed weight (mostly dressed, head-on):

Years	District 1 (Fraser R.)	District 2 (Northern)	District 3 (Southern)	B. C. Total
1945	2,289	14,350	14,418	31,057
1946	1,354	11,085	7,503	19,943
1947	1,464	8,507	10,173	20,143
1948	1,623	10,044	12,589	24,256
1949	1,129	9,715	10,845	21,688
1950	1,722	7,288	11,014	20,024
1951	1,221	13,818	17,171	32,211
1952	664	7,314	11,630	19,608
1953	662	6,806	13,677	21,105
1954	992	8,252	9,684	18,928

The sport fishery in the Strait of Georgia takes at least 200,000 small fish each year, and the commercial catch is approximately 3,000,000 fish per annum. Since 1945 the catch has remained fairly steady (20 to 30 million pounds). It constitutes about 15% by weight of the total British Columbia salmon catch. Since most of the coho salmon mature in their third year, the success of a large brood year is shown by the large catches in

1945, 1948 and 1951. The failure of the 1951 brood year is shown by the small catch in 1954. The poor return from the large run in 1951 can be attributed at least partly to the dry summer of 1952. Much of the variation in catch from year to year depends on summer stream flow and the survival of young coho salmon during their first year of life (e.g. Smoker, 1953). The low catch in District I and II in 1952 is due in part to a strike during the season.

Coho salmon are usually between 5 and 10 pounds in weight. Although most are used on the fresh and frozen market, a considerable number are canned.

Present Status

A number of coho tagging experiments has been conducted but there is apparently considerable mortality of troll-caught fish, and rate of return is usually not more than 10% even in the most recent experiments (e.g. Neave, 1951). It is also difficult to obtain escapement estimates from fish which disperse as widely as coho. However, the best estimates suggest that it is somewhat less than half of the stock, or about 2,000,000 fish out of a total of 5,000,000.

It seems inevitable that some coho stocks will gradually decline because of encroachment of civilization on the streams where they spawn and live during their first year of life. Also, logging of the watersheds will continue and will decrease the capacity of stream nurseries, though eventually an equilibrium should be reached in this respect.

As with the other salmons, coho face a deterioration of their freshwater environment. As the stream residence stage is vital to survival of coho, reduction in stream flows from logging and fires, by local diversions of water for irrigation or water supply, by ditching of farm lands, by construction of roads, and by industrial or agricultural pollution is more important to the coho than to the other species of salmon.

Installation of large power dams would also damage the coho stocks. However, because of the coho's wide-spread distribution, the effects of big dams would tend to be less on coho than on such species as the sockeye, whose distribution is more or less limited to larger river systems where immediate power developments are being considered. Also because of their wide-spread distribution the coho would probably benefit by the opening of new streams above obstructions more than any other species.

SPRING OR CHINOOK SALMON—*Oncorhynchus tshawytscha*

History

Spring salmon spawn in over 150 large to medium sized streams in British Columbia, of which the best 10% probably account for ¾ of the total fish. The young may spend up to a year in fresh water after hatching, but usually migrate to sea within a few months of emergence from the gravel. Maturity is attained in the third to eighth year, but usually in the fourth or fifth. Equalling or exceeding the sockeye in vigor, springs ascend to the headwaters of the Yukon, Skeena and Fraser, and formerly ascended to the headwaters of the Columbia as well.

Prior to 1945 accurate catch statistics are not available for spring salmon. However, estimates of the catch by types of gear from 1920 to 1945 suggest that in the early years the gill nets caught two-thirds of the catch and the trollers one-third. The gill net catch appears to have remained

relatively constant over the years, but from 1941 to 1946 the number of trollers increased rapidly, and they now take two-thirds of the total catch. Consequently the catch in the last decade is probably the highest in the history of the fishery. Since 1945 the annual catch (in thousands of pounds landed weight, mostly gutted, head-on) for the three administrative districts of British Columbia is shown below:

Year	District 1 (Fraser R.)	District 2 (Northern)	District 3 (Southern)	B. C. Total
1945	5,021	2,639	5,142	12,802
1946	3,695	4,038	7,498	15,231
1947	3,843	3,552	4,111	11,505
1948	2,646	3,394	7,467	13,508
1949	3,568	3,131	7,796	14,494
1950	2,970	2,703	7,794	13,466
1951	2,565	2,672	6,420	11,657
1952	2,133	3,274	7,464	12,870
1953	3,112	3,056	7,904	14,072
1954	3,304	2,531	6,403	12,237

During this period the catches in each of the three districts have remained relatively constant. The total commercial catch (10 to 15 million pounds, or about a million fish) constitute 8% by weight of the total British Columbia salmon catch. About 50,000 fish are taken by sport fishermen.

Spring salmon are large in size (usually 10 to 25 pounds), and many are used fresh or frozen. Most fish are mature or maturing when caught, but in certain areas trollers take many immature ones. As far as known, they hardly go to sea beyond the continental shelf. All are taken within sight of land.

The ocean migration routes and the origins of the stocks which are fished have been investigated by tagging and marking experiments. Spring salmon spawn mainly in the larger rivers, and the young move up the coast a long distance northwest from the rivers in which they spawn. Consequently, the Columbia River stocks are important in the Canadian and Alaska fisheries, and even Sacramento fish have been taken here (Clemens *et al*, 1939). It is estimated that in 1930 Columbia fish contributed over 50% of the troll catch outside the Strait of Georgia, but since then they have declined, until in 1950 they probably accounted for only about 30%. Formerly the spring and summer runs of Columbia springs were most important, but they declined as a result of water diversions and overfishing (apparently); when Grand Coulee dam cut off all spawners from entering Canada in 1939, chances of restoring populations were lost. In the last five years the late run to the Columbia River has also declined sharply. High catches in Canada have been maintained by increased numbers and efficiency of trolling boats, which has meant heavier exploitation of stocks from the larger rivers in British Columbia, such as the Fraser. Also, fishermen are catching smaller fish, and more of the immature fish, than formerly. In addition, more United States boats now fish off Vancouver Island, in Dixon Entrance and off southeast Alaska, than in the early years.

A small sport fishery has long operated in the Strait of Georgia. In recent years it has expanded rapidly and is spreading northward.

Present Status

Because spring salmon spawn in the upper tributaries and in the riffles of the larger rivers where observations are difficult, no very accurate measure of the spawning escapements is available. Best figures indicate that the spawners are less than half of the total stock, or about 500,000 fish.

Estimation of rate of exploitation from tagging results is difficult because of the unknown, but large, mortality of the fish after tagging. Also the international fishing and the long ocean migrations of the major stocks are complex, and make it impossible to estimate their individual size.

Since the recent increase in fishing effort has not produced any overall increase in catch, it seems likely that we are at or close to the highest yield which can be sustained by the available stocks as a whole. Some populations are probably too heavily fished; there is good presumptive evidence that the recent decrease of Columbia River fall chinooks is mainly a result of overfishing. As with the other species of salmon, the spring salmon rearing grounds are being endangered by the encroachment of civilization. A few important spawning streams have already been damaged by industrial use (e.g. the Nechako and the Puntledge). As spawning is mainly limited to large rivers and tributaries, the application of methods which show promise for pink and chum salmon would not be practical for springs. However some spawning areas can be opened up by fishways over natural obstacles.

Steelhead Trout—*Salmo gairdneri*

Present Status

The species, *Salmo gairdneri*, can be anadromous or can live wholly in fresh water; and the relations between the two types are obscure. Steelhead trout are identifiable as the returning anadromous individuals of the species. They occur in nearly all rivers along the British Columbia coast, sometimes in quite small ones. In appearance, size and habits steelhead greatly resemble the Atlantic salmon. However, steelhead appear to grow faster in fresh water and spend less time there (1-4 years, but usually not more than 2); and among the returning adults there is no sharp distinction between grilse and larger fish (Neave, 1949; Maher and Larkin, 1955). Sizes range up to about 25 pounds, with 15 pounds usually considered a big fish.

Steelhead trout are less common than any of the Pacific salmons, though the light fishery which many stocks experience suggests that the catch statistics do not do them justice. Per mile of coastline, they are apparently about as abundant as are Atlantic salmon in the East.

Steelhead runs in different streams may occur in summer or in winter; some streams have both types. Winter fish are commonest in coastal streams.

The commercial catch of steelhead is taken almost wholly by gill nets, since the species rarely takes a troll in salt water. The landings in recent years have been as below (weights are mostly dressed, head-on):

	No. of fish	Pounds
1951	—	408,200
1952	54,600	508,100
1953	43,100	363,200
1954	53,000	561,900

Largest catches are from the Skeena area; the Fraser yields about 10,000 fish.

However the commercial catch gives little indication of the abundance of steelhead, for most of the runs occur at places or times where there is little or no commercial fishery. There is a considerable subsistence fishery by Indians, using gill nets, dip-nets or gaffs. Its landings would be in the tens of thousands of fish, but no exact figures are available.

Sport fishermen take considerable numbers of steelhead in rivers, but again no comprehensive figures are available. Their fishing is heavily concentrated on the more accessible lower mainland and Vancouver Island streams, but it also extends up such of the larger rivers as are clear enough to fish, especially the Thompson, Bulkley and Babine. The only figures available for the take by sportsmen is a tentative estimate of 2,500 caught during the winter of 1948-49 in the Chilliwack-Vedder system (Larkin, 1949). The total must amount to some tens of thousands of fish. Sport fishing success varies greatly with the weather and with stream conditions. The take is not related either to commercial catch or to variable success of steelhead reproduction: in fact, successive year-classes seem remarkably uniform in numbers (Mather and Larkin, 1955).

In the province as a whole, steelhead seem to be relatively lightly fished. From accessible streams, however, there is presumably a heavier take. If overfishing occurs at all, it is only locally where, in addition to some commercial take, an intense subsistence fishery or sport fishery is fishing a rather small river.

Pacific Herring—*Clupea pallasi*

History

Herring have been fished in British Columbia waters since 1877, when a catch of about 75 tons was made. The largest annual catch of about 211,000 tons was made in the 1953-54 fishing season. In the table below are shown the average catches by 5-year periods from 1910-11 to 1950-51, and by season from 1950-51 to 1954-55, for each sub-district.

Average catch of herring (in tons) by 5-year periods from 1910-11 to 1950-51 and by season thereafter for each sub-district.

Year*	Queen Charlotte Islands	Northern	Central	Upper East Coast of Vancouver Island	Middle East Coast of Vancouver Island	Lower East Coast of Vancouver Island	West Coast of Vancouver Island	Total
1910/11-1914/15	353	3,009	3	..	..	20,504	1,758	27,627
1915/16-1920 ...	2	1,415	235	..	197	20,152	14,053	31,608
1921-1925	..	1,773	523	17	221	24,318	28,936	55,787
1926-1930	15	5,208	303	16	61	42,780	22,599	70,982
1931-1935/36 ..	11	4,765	69	75	14	23,956	21,813	50,703
1936/37-1940/41	3,400	14,560	31,580	3,760	3,320	28,060	25,720	110,400
1941/42-1945/46	500	4,420	21,600	4,700	7,090	42,940	18,180	99,420
1946/47-1950/51	630	30,350	38,100	5,840	12,150	39,570	44,520	171,160
1951-1952	11,200	57,300	39,900	8,250	10,350	41,000	30,000	198,000
1952-1953** ...	185	2,184	1,090	106	83	8,091	23	11,824
1953-1954	28,550	29,750	31,650	6,650	19,600	52,660	41,350	210,210
1954-1955	21,625	20,280	27,615	9,530	25,740	51,130	14,200	170,120

* Records from 1910 to 1916 represent the fiscal year which includes an entire herring season (October to February), records from 1917 to 1932 are for the calendar year, while those for 1933-34 onwards are for the herring season. The error introduced in using the calendar year is not great, as the major part of the fishery takes place by the end of December.

** Fishing effort was greatly decreased in 1952-53, as a result of a dispute between fishing companies and fishermen over prices.

Primarily in response to market conditions, the herring fishery has shown a steady expansion within the past 50 years, both in respect to size of catch and to number of stocks exploited. The most important influences have been the development and loss of the oriental market for dry-salt herring and the development of the reduction industry for herring meal and oil (Tester, 1945).

The dry-salt industry began in 1904, at a time when fishing was confined mainly to waters off the lower east coast of Vancouver Island. Commercial fishing operations expanded to the west coast of Vancouver Island in 1911-12 when Barkley Sound was fished for the first time. In response to this market, other areas on the west coast of Vancouver Island northwest of Barkley Sound were fished in 1926-27, and as a result the annual catch rose to about 85,000 tons in that season.

In the early 1930's the market for dry-salt herring declined, and the catch fell to 30,000 tons in 1934-35. The reduction industry, first established in 1924, made little progress in this period as a result of strong prejudice against this method of utilizing herring and the fact that catches on the west coast of Vancouver Island were more erratic than formerly. Fear developed that the west coast herring stocks had been depleted through overfishing, and concern was expressed that herring on the lower east coast of Vancouver Island might also become depleted. As a result, catch quotas were imposed in 1936-37 on both the west coast and lower east coast stocks. This, together with expanding markets, stimulated interest in fishing herring in other coastal areas which had hitherto been fished only slightly or not at all, and major fishing operations were begun in waters off the central mainland in 1936-37, the lower east coast of the Queen Charlotte Islands in 1938-39, the upper and middle east coast of Vancouver Island in 1939-40, and the northern mainland (Prince Rupert area) in 1939-40. By the early 1940's, the reduction industry was firmly established, and the annual catch averaged about 100,000 tons. At this time, all seven major herring populations, with the single exception of that of the east coast of the Queen Charlotte Islands were subjected to catch quotas.

In the mid-1940's doubt emerged regarding the need for catch quotas. It was shown that the abundance of a herring population was dependent upon the abundance of the constituent year-class and that the low catches which had occurred on the west coast of Vancouver Island were primarily due to the absence of particularly abundant year-classes for several successive years (Tester, 1948). The recovery of that fishery in 1945-46 resulted from the appearance of the rich 1943 year-class. Furthermore, it appeared that the production of strong or weak year-classes had not been caused by the amount of fishing. Small year-classes did not generally result from small spawnings, nor did large year-classes tend to result from large spawnings. For example, the strong 1943 year-class was derived from an exceptionally poor spawning.

These findings held important economic implications; quota restrictions may well have been wasting thousands of tons of herring annually. Interest in the quota problem reached a peak when a strong post-war European market (in the mid-1940's) was stimulating the development of

the herring industry. As a result, an experiment was planned to test the efficacy of the quota system—the quota was removed from one herring fishery (on the west coast of Vancouver Island) and the catches in this region followed for several years. Results of the experiment indicated that in some regions at least, limitations of catch by quotas were unnecessary.

Recent studies have suggested that annual variation in meteorological and oceanographic conditions have a profound effect on the survival of herring larvae. It would appear that such natural factors operating in early life have a greater effect on the strength of herring year-classes than the number of spawning fish that escape the fishery.

Since the introduction of the purse-seine into the herring fishery in 1910, this method of fishing has been used almost exclusively, less than one percent of the catch being taken by other methods in recent years.

Present Status

From 1947-48 to 1954-55, the annual herring catch has averaged about 190,000 tons. The substantial increase over the catch in the early 1940's is largely a result of greater exploitation of regularly-fished stocks. Only one small stock, that from waters off the upper east coast of the Queen Charlotte Islands, was fished for the first time in this period. While quota restrictions are still applied on most stocks, extensions to the quotas are readily granted when scientific information indicates that the stocks are obviously large. Further study on this question is being undertaken. About 98 per cent of the present catch is reduced to meal and oil.

Increased exploitation of the stock in recent years was facilitated by the widespread use of the echo-sounder in locating fish and of the radio-telephone for efficient deployment of the herring seining fleet.

Little precise information exists on the rate of exploitation of the various herring populations. The best information exists for the population of the lower east coast of Vancouver Island. Tester (1955) from age composition and catch data estimated that from 1942-43 to 1951-52 the average size of this population at the start of the fishing season was about 71,000 tons. During the same period the average catch was about 40,000 tons, giving an exploitation rate of 56%. Tester's estimate agrees well with that made by Stevenson and Outram (1953) obtained by adding the number of fish in the catch to the number in the spawning population, estimating the latter from the number of miles of spawn deposited after the close of the fishing season and relating numbers of miles of spawn to numbers of spawning fish. An estimate of the average size of the population on the west coast of Vancouver Island from 1946-47 to 1951-52 can be made by converting into tons and averaging Stevenson and Outram's (1953) estimate of the numbers of fish present at the start of each season. This yields an estimate of 91,200 tons. During the same period[1] the average catch was 42,100 tons, giving an average exploitation rate of 47%.

While no direct information exists on the exploitation rates in other populations, indications are that they are probably of the same order of magnitude as those for lower east coast and west coast of Vancouver Island populations. Based on the average rate of exploitation of the above

1 In 1952-53, because of a strike of herring fishermen there was no regular fishery. The small catch in this year is omitted in calculating the average catch.

two populations and on the average total annual catch of herring from 1947-48 to 1954-55 (omitting 1952-53) the average total population of herring in British Columbia amounts to 365,000 tons.

The lack of any relationship between amount of spawn deposited and abundance of resultant year-class suggests that the present exploitation can be increased without endangering the maintenance of the stocks. Research is now being carried out to determine the minimum size of spawning stock required to maintain the fishery at a maximum sustained level.

Pacific Halibut—*Hippoglossus stenolepis*

Halibut is first recorded as entering Canadian commercial production in 1888. Reasonably complete statistics date from 1915, which happens to be the high point of the early fishery, when 19 million pounds were reported. However, production started to decline immediately afterward. Subsequent Canadian catches are as shown below (Bell, Dunlop, and Freeman, 1952):

Years	Av. catch (millions of lb.*)	Year	Catch (millions of lb.*)
1916-20	8.9	1951	21.0
1921-25	9.1	1952	24.8
1926-30	8.6	1953	25.8
1931-35	8.5	1954	27.5
1936-40	12.3		
1941-45	13.2		
1946-50	19.9		

* Halibut catch statistics are in terms of gutted head-on weights.

After the 1915 peak, catches declined because decreasing fishing success made the fishery less profitable, until dissatisfaction led to formation of the International Fisheries Commission to investigate and eventually regulate the halibut fishery. This body, now the International Pacific Halibut Commission, has carried out these duties down to the present. The Annual Reports and other Bulletins of the Commission are the source of almost all available information concerning western halibut.

The Commission has divided the region fished by Canadians into 2 Areas. Area 2 comprises the coast from Willapa Harbour, Washington, to Cape Spencer, Alaska, and most of the Canadian catch comes from this Area. Area 3 which provided a Canadian catch of nearly 10 million pounds in 1954, extends from Cape Spencer west to the Aleutian Islands. Both Areas are also fished by United States vessels, which have traditionally taken the larger part of the catch in both, and still do in Area 3.

The fishery is mainly by long-lining. Trolling is permitted within the fishing season, and many trollers now turn their attention from salmon to halibut at that time.

Area 2

History

Catches by Canada *and* the United States, number of standard units of effort (6-line skates), and catch per unit effort, are shown below (Thompson and Bell, 1934; Thompson, 1950; Dunlop, 1951; and Schaefer, 1954):

	Yearly catch (millions of lb.)	Av. no. of skates set (thousands)	Catch per skate
1902, 04, 05	24.1	..	..
1907, 10	50.9	185	275
1911-15	52.8	353	149
1916-20	29.3	326	90
1921-25	28.8	477	60
1926-30	23.8	535	44
1931-35	22.3	431	52
1936-40	26.2	427	61
1941-45	25.3	347	73
1946-50	28.1	314	90
1951	30.6	319	96
1952	30.9	..	increased
1953	33.0	..	increased
1954	36.7	..	increased

The catch increased to a maximum in 1912, decreased to 1931, and soon after was brought under a quota regulation. The quota has gradually been raised.

The gear in use (that is, actually set) increased to 1929, declined somewhat with the economic depression, and since 1932 has been decreasing; in the latter period the increase in the catch quota has been less rapid than the increase in the catch per skate. On the other hand, the number of vessels fishing halibut has increased until the fishing season in Area 2 is now reduced to about a month, whereas formerly it lasted all year.

The abundance of the stock, as indicated by catch per skate, decreased in successive five-year periods until 1926-30. Since then, abundance has shown a gradual increase. The latter coincides with the application of annual catch quotas, and the Commission considers that prior to the establishment of catch quotas, the catch was too great for the maintenance of the stock. In general, it is not considered that abundance has been greatly influenced by natural factors except possibly in the case of certain short-term fluctuations. However, the possibility that changes in marine climate, in addition to fishing, have affected abundance is discussed by Ketchen (1956).

While catch per skate generally reflects abundance, its accuracy in doing so from one period to another in the history of the fishery is affected by certain factors, chief of which are (a) discovery of new fishing banks in early years, and (b) shortening of the fishing season in recent years.

Present Stock

Assuming that fish of 30 inches in length (about 12 pounds in weight) and larger are fully available to the fishery, from the tagging experiments of 1925 and 1926 (Thompson and Herrington, 1931) it can be estimated that the fishery took about 40% of a total available stock estimated at 43 million pounds. Considering (a) that this represented only fish that were fully available to the fishery and assuming (b) that as many or more fish moved from unfished areas to fished banks as moved away from fished banks, this estimate is likely minimal.

Preliminary analysis of recent tagging experiments indicate that the rate of fishing has decreased in recent years. Population abundance has certainly increased to a greater extent than catch as the catch per skate indicates. If the amount of gear in use can be used as a gross measure of rate of fishing, then fishing effort in the period 1946-50 has apparently been about one-third lower than in the 1920's. On this basis the total stock on the fishable banks during the 1946-50 period can be calculated at about 97 million pounds. Trends to 1954 would raise this figure to at least 105 million pounds. For reasons given above this is probably a minimum estimate of present abundance.

Relating the 1954 catch to the above estimate of abundance, it can be calculated that not more than 35% of the stock was taken by the fishery in 1954. The view of the Commission is that the present catch probably cannot be much exceeded, if the stock is to be maintained at maximum productivity.

Area 3

History

The fishery west of Cape Spencer began about 1912, but developed quickly and reached 22.1 million pounds in 1914. Catches by Canada and the United States, fishing effort, and catch per unit effort are shown below (Thompson and Bell, 1934; Thompson, 1950; and Dunlop, 1951):

	Yearly catch (millions of lb.)	Av. no. of skates set (thousands)	Catch per set
1915	23.7	89	266
1916-20	14.5	75	153
1921-25	20.5	167	126
1926-30	28.8	364	78
1931-35	22.6	271	82
1936-40	24.2	232	112
1941-45	27.4	209	134
1946-50	28.8	255	113
1951	25.4	..	(113)
1952	31.4	..	increased
1953	27.1	..	increased
1954	33.8	..	increased

As in Area 2, the fluctuations in fishing success generally reflect the change in stock on the fishing grounds, but the same limitations on the applicability of catch per skate as a measure of total stock apply here. A special feature of the Area 3 picture is a second small dip in catch per skate between 1944 and 1948, followed by a renewed rising trend.

Much of the original decline in catch per skate can be attributed to the removal of accumulated older stocks as in Area 2.

Present Stock

The 1926-27 tagging experiments in Area 3 were concentrated on winter spawning fish, and gave a rate of utilization of about 10 per cent. It has been suggested that this was probably too low to be representative of the whole stock, or at any rate of stock present on the summer fishing grounds. Recent taggings show low returns (from 2 per cent up to about 5 per cent

at most, per year), but these results are not considered to give a measure of exploitation of the stock. The best information available suggests that the present rate of fishing is at least 10 per cent. In view of the fact that the 1954 catch was about 34 million pounds, the stock available in that year was probably not more than 340 million pounds.

As in Area 2, the Commission considers that the present rate of exploitation cannot be increased greatly without interfering with future production. The low rate of exploitation in Area 3, as compared to Area 2, may result from the cooler temperatures, slower growth and late maturation of halibut in the more northerly area.

Groundfish

Introduction

Along the British Columbia coast the fishery for groundfish involves at least 30 species of demersal fish, which, as a group exclusive of the halibut, contribute an average of 52,000,000 pounds to the annual production (1950-54). Canada's share is obtained largely in competition with United States vessels in international waters and averages 23,000,000 pounds or roughly 50 per cent of this total.

The bulk of the catch is derived by otter-trawling, a method of fishing which came into prominence in the Pacific area during World War II. The remainder is obtained by older fishing methods such as long-lining and hand-lining.

Following initial expansion of the fishery, production of individual species has failed to stabilize. In the brief history of the fishery, emphasis has shifted from species to species and from bank to bank as the accumulated stocks have been removed. Much of the instability can be attributed to unstable markets. Demand varies not only from year to year but from species to species, and with differing effects on the fishing activities of the Canadian and American fleets.

Superimposed on the economic factors, and perhaps dominating them in the case of some species, are fluctuations in abundance. The causes have not as yet been accurately assessed. Detailed knowledge of the population parameters of many of the species is still lacking, and this adds to the difficulty of establishing a sound basis for prediction. The fishing banks along the British Columbia coast are relatively small in size and all are now within the general working range of the Canadian and United States fleets. Recent expansion of the fishery to deeper water and increased interest in species of lower quality, concomitant with declining yield of the more highly prized species, suggests that the present yield of some species at least is approaching the productive potential, in so far as foodfish for human consumption are concerned.

The present yield of groundfish utilized for human consumption is estimated at about 47,000,000 pounds. The present rate of exploitation for all foodfish stocks combined is estimated at about 12 per cent per annum. This is believed to vary from as low as 8 per cent in some species to as high as 27 per cent in others. The following table is a general summary of the size of groundfish stocks and of their exploitation along the British Columbia coast (catch figures based on the 1950-54 average).

Species	Present stock	Millions of Pounds Canadian catch	American catch	Total catch
Lemon sole	15	2.8	1.3	4.1
Brill	15	1.5	3.5	5.0
Rock sole	40	3.2	0.5	3.7
Butter sole	25	1.0	0.0	1.0
Dover sole	40	0.7	0.6	1.3
Gray cod	53	4.6	6.2	10.8
Lingcod	120	3.9	2.3	6.2
Rockfish—10 spp.	30	0.9	8.1	9.0
Blackcod	14	1.3	2.7	4.0
Other fish—10 spp.	20	0.7	0.9	1.6
Total foodfish	372	20.6	26.1	46.7
Animal food	40	2.4	1.0	3.4
Meal & liver (Dogfish)	600	1.0	0.7	1.5
Total all species	1,012	24.0	27.8	51.8

Lemon Sole—*Parophrys vetulus*

The fishery for lemon sole is entirely by means of the otter-trawl. It began in the Strait of Georgia prior to World War I as a small operation on banks close to Vancouver. A fishery by three steam trawlers began in Hecate Strait during that war but it was short-lived. During the 1920's and 1930's the fishery was confined almost entirely to banks within the Strait of Georgia, and remained at a low level supplying the local fresh fish demand. About 1940 the trawlers began to extend beyond the Strait to banks along the west coast of Vancouver Island. Substantial increase in the landing of lemon sole, however, came about only with the re-awakening of interest in the fishing grounds of northern Hecate Strait. This occurred towards the end of World War II with the great development of the market for fresh and frozen fillets.

As shown in the following table, lemon sole landings by the Canadian fleet during the 1930's averaged only half a million pounds annually. By the 1946-50 period, however, the average was close to two and a half million pounds, with a peak production of 5.4 million pounds in 1950.

Years	Av. catch in thousands of lbs.	Year	Av. catch in thousands of lbs.
1931-35	400	1951	2,158
1936-40	530	1952	2,537
1941-45	1,180	1953	2,340
1946-50	2,478	1954	1,472

Since 1950 the catch has varied between 1.5 and 2.5 million pounds.

Population studies suggest that the total commercial stock of lemon sole along the British Columbia coast is about 15 million pounds. The average annual yield from Canadian territorial waters in the 1948-54 period was about 0.5 million pounds. The international fishery of Hecate Strait has yielded 2.8 million pounds on the average, with Canada's share averaging 1.9 million pounds or 68%. Off the west coast of Vancouver

Island the average catch has been about 0.6 million pounds, of which Canada has taken on the average about 17% or 0.1 million pounds.

BRILL—*Eopsetta jordani*

The fishery for this flatfish takes place almost entirely in international waters. It began in the middle 1930's when United States trawlers started fishing off Cape Flattery (Cleaver, 1949). Canadian vessels appeared on grounds off the lower west coast of Vancouver Island about 1938, but did not become active participants in the fishery for brill until the early 1940's. During the war, vessels of both countries began moving farther and farther northward along the British Columbia coast, reaching Queen Charlotte Sound and Hecate Strait around 1944-45. Production by Canadian trawlers reached a peak of 7.7 million pounds in 1948, mainly through the discovery of dense concentrations on banks in middle Hecate Strait. Following that year, catch and catch/effort declined on nearly all grounds along the British Columbia coast. By 1954, as shown in the following table, the Canadian catch was less than a million pounds, and in 1955 it reached 0.5 million pounds, the lowest point in over a decade.

Years	Av. catch in thousands of lbs.	Year	Av. catch in thousands of lbs.
1931-35	..	1951	1,585
1936-40	95	1952	1,828
1941-45	430	1953	1,049
1946-50	3,172	1954	941

Concerning the *total* yield from the British Columbia banks, little is known for the years prior to 1948, since United States landings of flatfish were recorded neither by area nor by species before that date. Between 1948 and 1954 the total yield declined from 13.2 million pounds to 4.2 million pounds. The catches of the last two or three years would have been much lower had not the United States fleet discovered and exploited dense concentrations of spawning fish in deep water along the west coast of Vancouver Island. To date the Canadian fleet has not participated in this fishery, which occurs during the winter months.

In 1948-54 period the Canadian share of the total catch has averaged about 41% or 2.6 million pounds. But in the last two years it has amounted to only 20 to 30%. The Canadian share of the Hecate Strait and Queen Charlotte Sound catch has declined very sharply because of the failure of the brill to re-appear on the northern Hecate Strait grounds. The United States fleet on the other hand has been concentrating on the southern part of the Strait and on the Goose Island and Cape Scott grounds where Canadian vessels have been unable to compete effectively.

Two factors make it difficult to assess the present stock level. In the first place, efforts to determine rates of exploitation have been frustrated by the fact that the brill is highly migratory and seemingly erratic in its availability to fishing gear. Secondly, to judge from catch/effort records the stock is undergoing a rapid decline in size (Barraclough, 1954), and this dynamic situation complicates description of the stock.

On the important grounds off the west coast of Vancouver Island the catch/effort in 1954 was calculated to be between 42% and 47% of its value in 1948. In this same period the total catch declined to 32% of its 1948 value, but this is less reliable as an indication of the change in stock

size. There is some basis for assuming that the annual rate of exploitation was about 20% during the years when the brill was exploited in the spring and summer months only. With the advent of the winter fishery the annual rate has probably increased to 25%. The catch in 1954 was 4.2 million pounds and one million pounds of this was taken in the winter fishery. If we assume that the summer catch of 3.2 million pounds was taken at a rate of 20% we obtain a stock estimate of 14.5 million pounds. On the basis of the decline in catch/effort in the 1948-54 period, the stock in 1954 was only about 45% of that present in 1948. Hence, the 1948 stock is estimated as 32 million pounds.

Rock Sole—*Lepidopsetta bilineata*

The history of the trawl fishery for rock sole is somewhat similar to that of the lemon sole. In the period between the two World Wars the annual yield remained at a very low level, probably not exceeding 0.1 million pounds per year. This was taken almost entirely on various small banks within the confines of the Strait of Georgia. It was not until the middle years of World War II when trawlers began to take an interest in the grounds off the north coast (Queen Charlotte Sound and Hecate Strait) that there was a substantial increase in production of rock sole. Between 1943 and 1947, the Canadian catch rose from 0.5 million pounds to 2.6 million pounds, and then, after a brief recession, rose to a new peak of nearly 6 million pounds in 1952. Almost all of the Canadian catch has been taken on the Hecate Strait grounds.

The trend of the Canadian fishery is shown in the following table.

Years	Av. catch in thousands of lbs.	Year	Av. catch in thousands of lbs.
1931-35	110	1951	3,548
1936-40	100	1952	5,955
1941-45	557	1953	1,851
1946-50	1,929	1954	2,588

The Canadian catch in the 1948-54 period averaged about 2.85 million pounds, which represented nearly 88% of the total yield. Because of marketing difficulties the United States fleet continues to show little interest in the rock sole resource of British Columbia.

On the basis of tagging studies and mortality rates revealed by age composition, it is estimated that the stock of rock sole in Hecate Strait during the late 1940's was in the neighbourhood of 20 million pounds. However, between 1947 and 1955 there has been a marked increase in catch/effort, at least part of which can be attributed to increased abundance resulting from the passage of several strong year-classes through the fishery. If all the increase in catch/effort can be attributed to this increased recruitment, then the present stock is probably in the vicinity of 40 million pounds. However, allowing for other factors which may have contributed to the increase in fishing success, a conservative estimate of the present stock would be 30 million pounds.

Little is known of the stock in Queen Charlotte Sound, but it is suspected that the stock size does not exceed 10 million pounds. In all other areas of the coast the stock is probably no greater than 2 million pounds.

Thus, the total stock on British Columbia grounds is estimated to be about 40 million pounds. Tagging results suggest that the present rate of exploitation of the Hecate Strait and Queen Charlotte Sound stocks is 10% or less.

Butter Sole—*Isopsetta isolepis*

The commercial stock of butter sole in British Columbia waters is restricted to the Hecate Strait bank. This species is considered of lower quality than most other flatfishes, and is exploited only when general market demand is high. The fishery, if it occurs at all, is concentrated in the first few months of the year in Skidegate Inlet (Queen Charlotte Islands). Butter sole enter the Inlet from Hecate Strait and spawn during the months of January and February.

Commercial fishing began in 1943 with a catch of 0.5 million pounds. From 1944 to 1948 the catch ranged from as low as 0.1 million pounds to 1.75 million pounds. In 1949 and 1950 the fishery was a complete failure because the spawners failed to enter the inlet. As shown in the following table the Canadian catch reached an all time high of 3.5 million pounds in 1952. In the last two years the bulk of the catch has been processed as mink feed.

Years	Av. catch in thousands of lbs.	Year	Av. catch in thousands of lbs.
1931-35	0	1951	1,700
1936-40	0	1952	3,500
1941-45	656	1953	280
1946-50	313	1954	211

There has been no international fishery for butter sole. However, the United States trawler fleet utilizes stocks which inhabit the territorial waters of Puget Sound. Almost all of their catch is used for mink feed.

While tagging has given some indication of the rate of exploitation of the stock of butter sole which enters Skidegate Inlet, it has not shed any light on the rate respecting the entire stock in Hecate Strait. There are several indications that the Skidegate Inlet spawning run may be only a minor segment of the adult stock in the Strait. Using the rate of exploitation as computed for Skidegate stocks in 1946 (30%) then the minimum stock size must be of the order of about 10 million pounds.

To judge from the abundance of adult butter sole on the Hecate Strait bank during the summer months, it would be safe to estimate the total adult stock at more than double the above amount, say, 25 million pounds.

Dover Sole—*Microstomus pacificus*

The dover sole is another species of flatfish which, since the inception of the otter-trawl fishery, has been in relatively poor demand—not because of poor quality, but because of processing difficulties. The Canadian catch has varied from 0.1 to 0.9 million pounds since 1946 (the first year of exploitation), and as shown in the table below has averaged about 0.7 million pounds in the period 1951-54. The bulk of the catch comes from grounds off the southern part of Vancouver Island and in Dixon Entrance.

Years	Av. catch in thousands of lbs.	Year	Av. catch in thousands of lbs.
1931-35	0	1951	974
1936-40	0	1952	941
1941-45	0	1953	464
1946-50	420	1954	402

The United States catch (known only since 1951) has averaged about 1.0 million pounds, but only about 60% of this comes from grounds which are adjacent to British Columbia.

At the present day little interest is being shown in the dover sole, even though it appears to exist in considerable abundance along the British Columbia coast. No information is available on rates of exploitation or stock size, but it is presumed that the stock is of the order of 40 million pounds.

GRAY COD—*Gadus macrocephalus*

The Canadian fishery for gray cod began in the Strait of Georgia around the time of the first World War, but because of its low market value it was not pursued extensively or consistently. Between 1927 and 1940 annual catches rose somewhat irregularly from less than 100,000 pounds to more than 1½ million pounds, mainly as a result of increased local demand. During World War II there was little or no increase in the demand for gray cod, which is in contrast to the higher-priced groundfish. However, the demand increased sharply in the 1950's, to such an extent that the gray cod is now the dominant species in the trawler landings. A similarly late development of interest in the gray cod is noted in the trend of United States landings. This has stemmed in part from the increased demand produced by the "fish stick" industry. But the decline in abundance of other more desirable species may also have been a factor. There is also some suggestion that the gray cod may have increased in abundance within the past decade.

The trend in the Canadian catch of gray cod is summarized in the following table:

Years	Av. catch in thousands of lbs.	Year	Av. catch in thousands of lbs.
1931-35	781	1951	5,678
1936-40	1,480	1952	4,913
1941-45	1,203	1953	3,454
1946-50	1,952	1954	5,700

The average total yield of gray cod from grounds along the British Columbia coast was 9 million pounds per year in 1948-54. In the 1951-54 period alone, the catch averaged close to 12 million pounds. The Canadian share has averaged about 40% of the total production.

Precise information on the rate of exploitation of the British Columbia stock of gray cod is lacking, since tagging studies have been limited to small and probably unrepresentative populations. On the Strait of Georgia grounds where the fishing effort is intense, seasonal rates as high as 30% have been computed (Forrester and Ketchen, 1955). For present purposes it is presumed that the rate in the 1951-54 period with respect to all fishing grounds has averaged close to 20% per annum. During this period the average yield was 11.7 million pounds. Hence the stock is estimated at 53 million pounds.

Despite the high rate of removal from Strait of Georgia grounds there is as yet no evidence that the fishery is an important factor governing the supply of fish (Ketchen, 1955). Preliminary study of the age composition of the gray cod stock shows a high growth rate and a high natural mortality rate. The latter is probably of the order of 50% per annum.

LINGCOD—*Ophiodon elongatus*

The fishery for lingcod began in the Strait of Georgia as a small boat operation employing hand-lines. In the decade prior to World War II the Canadian catch ranged between 4 and 6 million pounds, with the Strait of Georgia providing more than 90% of this yield. During World War II the catch increased as a result of increased demand for fish protein and vitamin A from liver oil. It was during this period that the rapidly developing otter-trawl fishery began to take a significant share of the annual yield of lingcod, and extended the region of exploitation to more exposed sections of the coast.

Statistics of the Canadian catch (dressed weights) are contained in the following table:

Years	Av. catch in thousands of lbs.	Year	Av. catch in thousands of lbs.
1931-35	4,838	1951	4,741
1936-40	5,068	1952	4,233
1941-45	6,109	1953	2,740
1946-50	5,953	1954	3,805

In the decade following the war, the catch declined because of reduced demand. The hand-line fishery of the Strait of Georgia still contributed more than half of the total landings. The remainder was obtained mainly by the trawler fleet operating in international waters off the west coast of Vancouver Island and in Hecate Strait.

Off the west coast of Vancouver Island the Canadian trawlers and line vessels compete with those from the United States. The catch during the 1950-54 period was divided fairly evenly between the two countries. In Hecate Strait the United States catch is about twice as great as the Canadian catch, but only 10% of the total yield from all grounds along the British Columbia coast. About 36% of the total is taken by Canadian boats operating in territorial waters.

A rate of exploitation of 10% has been computed for the Strait of Georgia hand-line fishery from tagging conducted between 1939 and 1944. It was during this period that the Strait of Georgia fishery reached its greatest production. On the basis of the average annual yield obtained in that period the stock is estimated at about 40 million pounds (dressed head-off weight).

It is impossible to estimate the stocks of lingcod inhabiting grounds off the open coast because of the lack of information on the rates of exploitation. Tagging has shown that these stocks are quite separate from that in the Strait of Georgia (Hart, 1943). Large sections of the coast appear to provide the reef habitat required by the lingcod, but the type of fishery which could operate most effectively in such regions (i.e. hand-line) is non-existent. Strictly on the basis of area, in relation to that inhabited by the Strait of Georgia stock, it is estimated that the west coast of Vancouver

Island stock amounts to 30 million pounds, while that in Queen Charlotte Sound and Hecate Strait may be close to 50 million pounds.

Thus there is a possibility that the total stock of lingcod off the British Columbia coast is of the order of 120 million pounds.

Rockfish or Rockcod—*Sebastodes spp.*

The fishery for rockfish is pursued on a relatively small scale by Canadian otter-trawlers and line vessels. Ten of the 23 or 24 species which are found off the British Columbia coast are used by the fresh and frozen fillet trade and by the newly developed "fish stick" industry.

The rockfishes, as their name implies, live in dense shoals on or near rocky bottoms or reefs and are found over a wide range of depths from the inter-tidal zone to 250-300 fathoms. However, no one species extends over this entire range. Species inhabiting shallow water are taken by trawls and hand-line; those in intermediate depths mainly by trawls; and those in deep water mainly by long-line and trawls.

Prior to the expansion of the trawl fishery during World War II, almost all of the catch was landed as an incidental product of the hand-line fishery for lingcod and the long line fishery for blackcod. As shown in the following table of Canadian landings, an interest developed in the trawl fishery specifically for rockfish during the war years; but this was short-lived. Between 1947 and 1953 the trawl landings of rockfish were merely incidental to those of other species. With the recent development of the "fish stick" market there has been some awakening of interest in a species known to the trade as Pacific "ocean perch" *(Sebastodes alutus)*.

Years	Av. catch in thousands of lbs.	Year	Av. catch in thousands of lbs.
1931-35	252	1951	938
1936-40	337	1952	916
1941-45	1,968	1953	955
1946-50	1,390	1954	939

In contrast to the Canadian fishery, the United States trawl fishery for rockfish has been very active along the British Columbia coast for more than a decade. Since 1945 their average annual rockfish catch has been over 9 million pounds, and for the most part has predominated over catches of other species.

There is very little information available for consideration of stock sizes of this group of species. It is known that the rockfishes are exceedingly slow growing and that maturity is probably not reached before 10 years of age.

The United States fishery has presumably depended on accumulated stocks of very old fish. The fact that increasing interest has been shown recently in stocks of rockfish species which formerly were avoided (small species such as the "ocean perch"), suggests that the accumulated stocks of the larger species have now been considerably reduced. About 70% of the United States catch of rockfish in 1954 was of "ocean perch". Furthermore, there has been a shift in fishing effort to deeper water, which suggests that stocks in shallower water are smaller.

Even at the present day there are no catch statistics of rockfish *by species*. Thus, it is impossible to assess the trends of exploitation as the

emphasis of the fishery progressed from species to species. Without such information, and data on mortality rates, it is impossible to make much more than a guess at present stock sizes. Even if we presumed that in 1945 the stock of *all* rockfish was as much as 100 million pounds, it is unlikely that the stock today is more than 30 million pounds.

BLACKCOD—*Anoplopoma fimbria*

The blackcod fishery is one of the few ocean fisheries with a long history in British Columbia, having been in existence since before the turn of the present century. Its main characteristic is that it is pursued almost entirely by long-lining in relatively deep water (100 to 250 fathoms). The Canadian catch is taken entirely in international waters, and on the average over the past 40 years has amounted to about a quarter of the total production from waters of the northeast Pacific.

Demand for fish protein during World War I caused the catch to rise to a peak of 8 million pounds, but a sharp decline followed immediately thereafter. From 1920 to 1940 the landings fluctuated at a low level of less than 2 million pounds per annum, reaching a low point of 0.5 million pounds during the economic depression. (See table below.)

Years	Av. catch in thousands of lbs.	Year	Av. catch in thousands of lbs.
1931-35	622	1951	1,897
1936-40	1,041	1952	1,347
1941-45	1,881	1953	1,364
1946-50	1,922	1954	1,128

The demands for foodfish and vitamin oil resulted in an upward trend in catch after 1940 to about 2.4 million pounds in 1946. Since that time the fishery has fluctuated considerably because of unstable market conditions, but in 1949 the catch reached 2.8 million pounds, its highest point since 1918.

In comparison with the fisheries for other groundfishes, competition for blackcod between Canadian and United States fishermen is not great, since there is little over-lap in their respective fishing areas. The Americans fishing out of Washington ports concentrate their efforts off Cape Flattery and along the southwest coast of Vancouver Island. The Canadian fleet operates from the northwest coast of Vancouver Island northward along the Queen Charlotte Islands and the coast of Alaska. The United States fishermen operating out of Alaskan ports fish almost exclusively in channels inside their territorial waters.

There is good evidence that the stock of blackcod fished by the United States fleet off Cape Flattery and Vancouver Island is overfished (Bell and Pruter, 1954). Catch per "skate" of gear has now stabilized at a low level of about 50 pounds. It is only in this area that otter-trawlers compete with hand-liners for blackcod. United States trawlers take 20% of the fish removed from the Cape Flattery area.

At the northern end of the range, off the Alaska coast, the stock appears to be underfished. Average catch per skate on the various grounds in this area is about 100 pounds, and fluctuations in catch can be traced entirely to fluctuations in demand (Edson, 1954; Ketchen and Forrester, 1954).

As yet there are no good estimates of rates of exploitation, since it has not been possible to devise a satisfactory method of tagging. For present

purposes it is presumed that the rate off southern Vancouver Island is at least 30%, and that off the remainder of British Columbia and off Alaska is no more than 15 per cent. Since the Canadian catch in the 1950-54 period averaged 1.33 million pounds the stock is estimated at about 8 million pounds. If we add in the stock off the southern coast of Vancouver Island which is exploited almost exclusively by the United States fleet (estimated rate of exploitation 30%) and take the average catch from that area as being about 2.0 million pounds, we obtain an estimate of 5.5 million pounds. The total stock for the British Columbia coast (and part of Alaska) is therefore estimated at about 14 million pounds.

Other species of groundfish:

Rex sole—*Glyptocephalus zachirus.*
Starry flounder—*Platichthys stellatus.*
Sand sole—*Psettichthys melanostictus.*
Flathead sole—*Hippoglossoides elassodon.*
Yellow-fin sole—*Limanda aspera.*
Big skate—*Raja binoculata.*
Viviparous perch—mainly *Damalichthys vacca.*
Ratfish—*Hydrolagus colliei.*

The above eight species of groundfishes are considered here as a group for the sake of brevity, even though such consideration may not be entirely meaningful. They are usually taken incidentally to the otter-trawl catches of other species and have been utilized in varying degrees for little more than a decade. The combined catch in the 1948-54 period has averaged 0.6 million pounds, but as shown in the table below, it has ranged from 0.3 million to 0.9 million pounds. Flounder and rex sole have comprised about three-quarters of the total yield.

Year	Catch in thousands of lbs.	Year	Catch in thousands of lbs.
1948	321	1952	928
1949	438	1953	406
1950	692	1954	516
1951	879		

Some of the incidental trawl-caught species fetch good prices(rex sole, sand sole, yellow-fin sole, perch), but fisheries specifically for such species have never developed, presumably because they were of low abundance even when unexploited. The situation is less clear for low priced species (starry flounder, flathead sole, ratfish), as no information is available on rates of exploitation or changes in abundance.

The stock of all these species combined probably does not exceed 20 million pounds.

Scrapfish for mink food:

Turbot or arrow-tooth sole—*Atheresthes stomias.*
Whiting or big-eye—*Theragra chalcogramma.*
Hake—*Merluccius productus.*
Small quantities of other species.

The fishery specifically for scrapfish is of very recent origin, having started in a small way in 1948. By 1955 it was the dominant feature of the British Columbia trawl fishery. The demand is being supplied mainly

by turbot and whiting, and to a lesser extent by hake, butter sole, dover sole and gray cod.

Prior to the 1950's the needs of fur-farms were satisfied by the supplies of offal from fish filleting plants. By 1951 the demand for scrapfish had greatly exceeded the supply of fillet scraps, as well as of horsemeat. Thus, trawl fishermen began landing large quantities of whole fish of species unsalable on the foodfish market. The trend of the Canadian fishery is shown in the following table:

Year	Catch in thousands of lbs.	Year	Catch in thousands of lbs.
1948	35	1952	1,392
1949	59	1953	2,298
1950	37	1954	2,843
1951	414	1955	5,676

At present the fishery is concentrating on the turbot, which is found almost entirely on grounds in international waters. However, in the winter months, when weather prevents fishing on the exposed grounds, emphasis turns to the whiting.

It is impossible to estimate accurately the sizes of these stocks, as they have only recently been subjected to exploitation. For present purposes the stock is estimated as being about 40 million pounds.

Dogfish—*Squalus acanthias*

The fishery for dogfish began in the early part of the present century by means of seine nets and hook and line. The entire catch was reduced to meal and oil. About 1940 the discovery of high vitamin A concentrations in dogfish brought about a marked change in the industry. While interest in the reduction of dogfish carcasses was maintained until 1944, there was a sharp upward trend in the fishery solely for the livers, so that large quantities of carcasses were discarded (see the schedule below; the liver averages 15% of the body weight). This was accomplished by otter-trawls, sunken nets and long-lines. By 1945 it was no longer profitable to use dogfish for reduction, presumably because the stock had been reduced to such an extent that continuity of supply became uncertain. In some areas the catch of dogfish per unit effort declined by 50% during the early 1940's (Barraclough, 1948a).

Average catch in thousands of pounds:

Period	Liver	Carcasses	Total utilization	Total captured
1926-30	0	15,597	15,597	15,597
1931-35	0	8,276	8,276	8,276
1936-40	3,131	12,904	16,035	20,900
1941-45	5,176	6,936	12,112	34,500
1946-50	2,835	0	2,835	18,900
1951	997	36	1,033	6,600
1952	760	199	959	5,100
1953	777	245	1,022	5,200
1954	626	211	837	4,200

Following the war, declining demand for vitamin products and reduced abundance of dogfish caused the annual yield to decline. By 1950 the full effects of the production of synthetic vitamin A and the importation of foreign products was shown in the greatly reduced landing. Between 1950 and 1954 the landing of liver remained at a very low level, while there has been a slight increase in the landing of carcasses for reduction.

In consequence of the cessation of fishing for dogfish, the stock now appears to be in the process of a strong recovery. Already, the dogfish has become a plague on many of the British Columbia fishing grounds—disrupting the trawl and seine fisheries for other species.

There are no accurate estimates of the rate of exploitation during the period of intense fishing during the 1940's. We know that the dogfish grows very slowly and that it reaches an advanced age (Bonham *et al*, 1949). We know also that during the period 1940-45 the accumulated catch by the Washington and British Columbia fleets was about 500 million pounds. If we neglect the effects of recruitment and natural mortality and assume that the accumulated catch was half the stock present in 1940 (based on a 50% reduction in catch/effort), we concluded that the original stock was of the order of one billion pounds. The present stock is presumed to be somewhere between 500 million and a billion pounds.

Sharks Other Than Dogfish

Soupfin shark—*Galeorhinus galeus.*
Basking shark—*Cetorhinus maximus*
Spotted cow shark—*Notorhynchus cepedianus.*
Mud shark—*Hexanchus griseus.*
Mackerel shark—*Isurus nasus.*
Blue shark—*Prionace glauca.*

Soupfin Shark—This is a small shark, growing about 6 feet long. It is mainly a summer visitor to British Columbia. The stock is probably migratory along considerable lengths of the coast: a fish tagged in California was taken off British Columbia (Foerster, 1945).

Because of the exceptionally high vitamin A potency of the livers of soupfin sharks, a fishery for this species was actively pursued during and shortly after World War II (Barraclough, 1948b). In the period of 1941-45 the averaged landed quantity of soupfin shark livers was about 40,000 pounds per year. By 1947 the quantity had decreased to 10,300 pounds. At the present time few are taken, and then only incidentally to other fishing operations.

The soupfin shark was caught mainly in Hecate Strait and off the west coast of Vancouver Island. A variety of fishing gear was used, but sunken gill nets set primarily for dogfish accounted for most of the catch. Catch per unit of effort reached a peak in 1944, the year when the largest catch (62,000 pounds of liver) was made. In subsequent years, when fishing effort was still high the catch per unit of effort decreased sharply, suggesting that abundance had been reduced by the fishery. However the Canadian catch was only part of the yield taken from the migratory stock.

Little is known of the present abundance of soupfin sharks, but it seems unlikely that they are as abundant now as they were before the war. Presumably a future fishery could be maintained on a sustained basis only providing that exploitation is less intense than during the war years.

Basking Shark—The basking shark grows to about 40 feet long. It has never been specifically fished in British Columbia. During the war years it was taken incidentally in salmon gill nets and sunken dogfish nets. At that time the value received for the liver defrayed the cost of repairing the damaged nets, but today it is only a nuisance. In recent years some effort has been directed to destroying these sharks by shooting or ramming them, because of their damage to gill nets.

Other sharks—The other species of sharks listed above are all fairly large. All are reported to be fairly common at some time or other in British Columbia waters, and are taken incidentally in other fishing operations—usually interfering with the latter. Present indications, however, do not suggest that commercial operations for these species are likely to be profitable in the foreseeable future.

Smelts

Eulachon—*Thaleichthys pacificus.*
Silver smelt—*Hypomesus pretiosus.*
Capelin—*Mallotus catervarius.*

Smelts are fish of a few ounces weight, which occur in dense shoals in spawning season. They are of minor commercial importance in British Columbia, but support important sport or subsistence fisheries. Three species are of some importance. Their occurrence and utilization was summarized by Hart and McHugh (1944).

Eulachon—This species spawns in the lower reaches of large rivers, up to 50 miles or so upstream. The recent Fraser River catches in thousands of pounds have been as follows:

Year	Catch	Year	Catch
1941	132	1948	363
1942	214	1949	298
1943	210	1950	189
1944	133	1951	311
1945	205	1952	744
1946	170	1953	218
1947	285	1954	334

Considerable quantities taken locally in dipnets are not included above. On other rivers eulachon are taken only on a subsistence basis, but the quantity is quite large, especially on the Nass (about 900,000 lbs. estimated in 1940).

A recent study of Fraser River catch and effort statistics for 1941-53 suggests that somewhat greater utilization should be possible, but that year-to-year variations will persist. However the species is vulnerable to possible pollution of the lower Fraser by expanding industrialization.

Silver smelt—This is or was *the* smelt of British Columbia fresh fish markets. It is taken mainly by gill nets on the ocean beaches where it spawns from June to September. Commercial catches have decreased from a high of 450,000 pounds in 1902-08 to about 25,000-50,000 pounds in recent years (Hart and McHugh, 1944). Causes of the decline may include contamination of preferred spawning beaches, especially in the Vancouver area, and overfishing.

Smelt occur at various places along the coast, and future production may increase somewhat if additional stocks are used. However, no very substantial increase in landings is anticipated.

Capelin—Usually called smelt in British Columbia, this species spawns in autumn in the Strait of Georgia, and in spring farther north. Some thousands of pounds of spawning fish are taken locally by dipnet, but none is put to commercial use.

Tuna or Albacore—*Thunnus alalunga*

History

The first albacore was recorded from British Columbia waters in 1938 and the first commercial catch was made in 1939. The fishery is by trolling with artificial lures. Canadian fishermen have operated south to waters off central California. The general eastern Pacific fishery is described by Brock (1943), and that of British Columbia by Partlo (1955).

The catch landed in British Columbia, in thousands of pounds, was as follows:

Year	Catch	Year	Catch
1939	284	1948	2,175
1940	5	1949	2,231
1941	76	1950	2,119
1942	0	1951	190
1943	29	1952	157
1944	464	1953	11
1945	1,289	1954	0
1946	432	1955	0
1947	796		

Albacore are caught in warm blue oceanic water during the months of July, August and September. The fish taken off our coast appear to be at the northern limit of the range of the eastern Pacific population, which is fished as far south as Baja California. The largest British Columbia catches were made from 1948 to 1950, with many caught offshore to the south. In 1951 only 14,000 pounds, out of the 190,000 pounds landed, were caught off British Columbia, but in some of the earlier years a much higher fraction was locally-caught fish. Since 1951 none has been caught off British Columbia and few have been taken north of California. None was landed here in 1954 or 1955.

There have been extreme periodic fluctuations in the eastern Pacific catch which as yet are unpredictable. The California fishery, which is the largest one, was good from 1915 to 1925 (peak of 30,000,000 lb. in 1917), almost negligible from 1928 to 1935, and good from 1938 to the present (record year 1950, with 62,000,000 lb.).

It has not been established whether or not the stocks that are fished off North America are separate from those fished off the Hawaiian Islands and Japan. Racial studies have suggested that they are distinct but recent tagging experiments show some trans-Pacific movement. Oceanographic surveys and exploratory fishing are now proceeding very actively in the north Pacific. To 1955 their results indicate an association of albacore with water of the eastward North Pacific current having temperatures above

14°C. The population which now supports a fishery extends from Japan to north of Midway Island across the Pacific until it meets the cold water near our coast.

Present Status

Since the ocean distribution of the populations which are now fished has not been determined, it is impossible to estimate the size of the stocks now being exploited. At the present time there is no definite prospect of catching many fish inshore north of California. There is, however, a fair possibility that current oceanographic surveys and exploratory fishing will discover albacore in commercial quantities within reach of sea-going boats such as the existing halibut fleet.

Pilchard—*Sardinops caerulea*

A purse seine fishery for pilchards was begun in British Columbia waters in 1917. In the early years of the fishery, up until 1924, the small catch was mostly canned. Beginning in 1925 the catch greatly expanded, and an important industry was founded on the reduction of pilchards to meal and oil (Hart, 1933).

In the 30-year period of the fishery, the catch fluctuated widely. These fluctuations resulted from changes in the abundance of the fish, variations in the availability of fish to the fishery (independent of their abundance), and changes in market demands. Since 1947, as a result of drastically reduced abundance no pilchard fishery has developed.

The pilchards of the British Columbia coast are part of a stock occurring as far south as California. Spawning occurs off California and the young remain in these waters. The adults migrate extensively, especially the larger ones, and in periods of high abundance sufficient numbers move into waters off British Columbia to provide a fishery. The recent decline in the abundance of pilchards has resulted from the failure of the population to reproduce itself during a period of heavy exploitation in California waters, and of low ocean temperatures.

The catches of pilchards in British Columbia waters were as follows:

Year	Av. catch in tons	Year	Av. catch in tons
1917-20	2,850	1936-40	35,718
1921-25	4,060	1941-45	61,609
1926-30	71,770	1946	3,990
1931-35	42,064	1947	440

Anchovy—*Engraulis mordax*

Since 1939 a small fishery on anchovies has been carried on in coastal waters of British Columbia. Although anchovies were taken as far north as Ogden Channel, a large proportion of the catch was taken in southern waters of the province, mostly near shore on the west coast of Vancouver Island. The fishery has taken place on small, self-sustaining local populations which spawn in bays and inlets during June, July and August. These inshore stocks appear to be distinct from the large spawning populations which occur offshore from California to Washington and possibly as far north as British Columbia.

The average annual catch in recent years, in thousands of pounds, was as follows:

Years	Av. catch	Year	Av. catch
1939-40	4,700	1951	Nil
1941-45	4,900	1952	170
1946-50	1,350	1953	750
		1954	10
		1955	Nil

During the early years of the fishery, a large part of the catch was reduced to oil and meal, but in recent years the catch has been mostly canned. It appears that the reduced catch in the past 10 years is a result of decreased demand.

While little information exists on the future potential of the anchovy stocks, it appears unlikely that sustained yield would greatly exceed the catches of the early 1940's. This is from the inshore-spawning stocks. The oceanic-spawning population is of unknown size and distribution.

Miscellaneous Pelagic Species

Pacific mackerel—*Pneumatophorus diego.*
Jack mackerel—*Trachurus symmetricus.*
Saury—*Cololabis saira.*
Ragfish—*Acrotus willoughbyi.*

The presence of these species in waters off the west coast of Vancouver Island is known chiefly from their occurrence mixed in catches of pilchards, or in the stomachs of sperm whales. Information on their abundance is lacking, but one or more may eventually support a commercial fishery, given appropriate advances in fishing technique or in market demand.

Crab—*Cancer magister*

History

The commercial crab is generally found on a sand bottom at depths of ten fathoms or shallower. The mature crabs usually breed during the summer months. The eggs are spawned in the autumn, and retained on the abdomen of the female. She carries the eggs during the winter until they hatch in the spring as free swimming larvae. After about four months, the young crabs settle to the bottom to begin their adult lives (MacKay, 1942).

Growth of the juveniles is accompanied by frequent moulting, and both sexes mature during the third year. The male usually reaches legal size during the fourth or fifth year.

Crabs were fished commercially in British Columbia before 1890. In 1915 crab fishing was being carried out at Victoria, Nanaimo, Boundary Bay, Burrard Inlet and Prince Rupert (Weymouth, 1916). In the Queen Charlotte Islands the commercial fishery was started in 1917 (McMynn, 1951).

Crab landings (in thousands of pounds) from British Columbia waters, 1921-1954, with United States catches from Hecate Strait in 1950 to 1954 are shown in the following table:

Years	Canada	Landings U.S.A.	Total
1921-25	737	..	..
1926-30	687	..	..
1931-35	528	..	..
1936-40	946	..	..
1941-45	848	..	..
1946-50	1,886	880 (1950)	2,766
1951	1,811	961	2,772
1952	1,999	1,169	3,168
1953	3,193	1,396	4,589
1954	4,188	949	5,138

Present Status

The major fishing grounds are around the Queen Charlotte Islands in Hecate Strait and Dixon Entrance, along the west coast of Vancouver Island, in Boundary Bay and in Burrard Inlet. Hecate Strait has been exploited jointly by Canadian and United States vessels since 1950; the share of the latter averaging 64% of the total catch of the area. The greater part of the crab catch is taken by traps; the remainder is caught by trawlers incidentally to the capture of groundfish. Since the female crab seldom reaches the legal size limit of 6½ inches, the fishery in practice is limited to male crabs.

Considerable fluctuations in numbers of young crabs occur at least in the Queen Charlotte Islands region. Tagging experiments (e.g. Butler, 1951) have shown that crabs perform seasonal migrations in this region. Also, tagging experiments and catch statistics indicate that the fishery is at present fairly heavily exploited (60-80% per year) and depends largely upon the annual recruitment.

Shrimps and Prawns—*Pandalus spp.*

History

Six species of commercial shrimps are found on the British Columbia Coast. Five species are found on mud or sand bottoms, and are taken commercially by small-meshed trawls in depths up to 60 fathoms. The other species, the "prawn" is taken by traps on rock bottoms.

A fishery was in existence before 1890, when shrimps were being fished near Victoria (Rathbun, 1900). Practically no information regarding the development of the shrimp fishery is available, but trawling in Burrard Inlet began at a fairly early period, and this is still an important source of supply.

The main features of the life histories of the shrimps are known (Berkeley, 1930). Mature individuals of all species breed in the late autumn or early winter. The developing eggs appear on the abdomen of the female shortly after breeding, and are carried during the winter months. The young are hatched in the early spring and swim freely for about three months before settling to the bottom. The shrimps mature first as males in the first or second year, depending on the species. After one or two seasons as sexually active males, these shrimps change sex and function as females for the rest of their lives.

British Columbia shrimp and prawn landings, 1921-54 ("green" weight, in pounds) are given in the following table:

Years	Landings	Year	Landings
1921-25	91,000	1951	545,300
1926-30	111,600	1952	824,700
1931-35	154,500	1953	1,258,600
1936-40	107,800	1954	951,000
1941-45	54,200		
1946-50	280,200		

Present Status

Shrimp fishing is carried on in Burrard Inlet, Howe Sound, the east coast of Vancouver Island, and in Chatham Sound, near Prince Rupert. A definite estimate of present stocks is unavailable, because recent exploratory fishing has resulted in discovery of new stocks (Butler and Dubokovic, 1955a, 1955b), and further search is expected to locate additional supplies. Also, we can only guess at the rate of utilization of stocks currently in production—possibly 50% per year.

Since relatively little is known concerning the biology of shrimps, no active management can yet be contemplated. There are no regulations at present.

All currently-exploited shrimp grounds are located within Canadian territorial waters. Exploratory fishing in international waters has not found shrimps in numbers sufficient to support a commercial operation.

Edible Molluscs

The edible molluscs of British Columbia include oysters, various kinds of clams, scallops, abalones, squids and octopus. They have been described by Quayle (1941), who lists 21 species or groups of species. Most of these are not sufficiently abundant or sufficiently in demand to provide significant commercial production at the present time, but nearly all are used to some extent by a recreation or subsistence fishery.

Two introduced species are among those which provide commercial yields, and one of them, the Pacific or Japanese oyster, is our most important shellfish at the moment.

Pacific Oyster—*Crassostrea gigas*

The history of oyster production in British Columbia begins about 1913, but it is only for the last 15 years or so that accurate production figures are available. The yields shown below are in United States gallons, to the nearest hundred. (1 U.S. gallon is 5/6 of an Imperial gallon, or about 8 pounds of oyster meat. Prior to 1946 the quantities were reported in 200-pound barrels of whole oysters; they have been converted at the rate of 1 barrel=2.5 U.S. gallons of meats.)

Year	Yield	Year	Yield
1940	21,700	1948	46,200
1941	91,200	1949	59,800
1942	37,400	1950	62,700
1943	37,700	1951	59,000
1944	49,700	1952	81,200
1945	35,200	1953	66,500
1946	65,800	1954	85,900
1947	61,700	1955	83,900

Nearly all this production comes from inter-tidal leased oyster grounds, mostly in the Strait of Georgia.

Potential oyster-growing capacity of suitable grounds in British Columbia is about 200 gallons per acre per year. Any individual first-class ground is best harvested every third year, at which time the crop is about 600 gallons per acre; poorer grounds are harvested less frequently. Today there are about 1,500 acres of usable ground under lease, of which about 400 acres would be harvested each year under full utilization. At present, however, some grounds are rarely harvested at all, and the average production of the 1,500 acres above is 220 gallons per acre per year, or about a third of their potential.

The reason for the low production of present beds is inadequate seeding, since seeding in best commercial quantities must be done artificially. Prior to 1951 nearly all seed was imported from Japan, but since that time an adequate local source of seed has been discovered and is being utilized. This source is reliable in nearly all years.

With adequate seeding, the oysters produced on existing leases can be expanded to at least 250,000 gallons per year.

Butter Clams—*Saxidomus giganteus*

The butter clam is found widely in British Columbia waters. A review of its occurrence and fishery has been made by Neave (1946).

The catches of recent years are as follows, in thousands of pounds (including shells):

Years	Yield	Years	Yield
1940-41	2,435	1948-49	1,626
1941-42	3,032	1949-50	2,640
1942-43	2,893	1951	3,500
1943-44	2,239	1952	5,492
1944-45	3,508	1953	3,691
1945-46	4,021	1954	2,897
1946-47	6,315	1955	2,762
1947-48	?		

No good information on present rate of utilization is available, but we estimate it at 20% per year for the province as a whole. Individual areas, when dug, have up to 75% of their commercial clams removed.

Razor Clams—*Siliqua patula*

The razor clam inhabits sand beaches of our coast, especially around the Queen Charlotte Islands. Recent commercial production (in thousands of pounds) including shells, is as follows:

Years	Yield	Years	Yield
1941-42	590	1948-49	223
1942-43	390	1949-50	176
1943-44	298	1951	136
1944-45	145	1952	126
1945-46	217	1953	154
1946-47	98	1954	272
1947-48	?	1955	178

Production today is limited by the weather and availability of diggers.

Little-neck Clams—*Protothaca staminea* and *Venerupis semidecussata*

Up to the middle 1930's only the native little-neck *(Protothaca)* occurred in British Columbia. The Japanese little-neck or Manila clam was introduced accidentally with oyster seed, was first distinguished in the statistics in 1951, and now surpasses the native species in commercial importance. Both species occur, in commercial quantities, almost solely in the Strait of Georgia.

Recent production in thousands of pounds, including shells, is as follows:

Years	Yield Native	Years	Yield Native	Yield Manila
1941-42	200	1948-49	436	..
1942-43	249	1949-50	842	..
1943-44	238	1951	522	179
1944-45	369	1952	493	496
1945-46	548	1953	309	388
1946-47	?	1954	138	450
1947-48	?	1955	79	439

Other Molluscs

Abalone—*Haliotis kamtschatkana.*
Scallops—*Pecten caurinus.*
Horse clams—*Schizothaerus nuttalli.*
Geoducks—*Panope generosa.*
Mussels—*Mytilus edulis* and *M. californianus.*
Cockles—*Cardium corbis.*
Mud-clams—*Mya arenaria.*
Octopus—*Octopus hongkongensis.*
Squids—*Loligo opalescens* and other species.

Abalones occur mostly on open coasts, from low tide level to several fathoms depth, and support a very small fishery. A recent limited survey failed to reveal densities which would permit expanded commercial utilization.

The *scallop* above is of commercial size, but exploration to date has not revealed commercial concentrations.

Horse Clams are abundant in parts of the Strait of Georgia and elsewhere, and were once an important part of the native diet. At present no market exists for this large and rather coarse species.

Geoducks are too scarce in British Columbia to be of interest except to sportsmen. They occur in a few places in the Strait of Georgia.

Mussel stocks are very large, but demand does not permit commercial utilization at present.

Cockles are abundant on some sandy beaches, but are not usually marketable.

Mud-clams do not occur in sufficient concentrations in British Columbia to permit commercial utilization. (This is the commercial clam of the east coast.)

Octopus usually do not exceed 2 feet in length in our waters, and are only occasionally used for food. They are found in rock crevices, usually below low-tide mark. About 75,000 pounds a year are used for bait.

Squids of the genus *Loligo* grow to about 8 inches long. The size of British Columbia stocks is not known and they are used in only insignificant quantities, though a fishery exists in California and they are extremely important in Asia. Small quantities of a larger squid *(Gonatus)*, about 2 feet long, are taken by trawlers in deep water and used in preparing oriental foods. Squids of the genus *Moroteuthis* grow to a length of about 12 feet. The latter two genera of squid are found in considerable abundance in sperm whale stomachs.

WHALES

Finback whale—*Balaenoptera physalus.*

Blue whale—*Balaenoptera musculus.*

Humpback whale—*Megaptera nodosa.*

Sei whale—*Balaenoptera borealis.*

Sperm whale—*Physeter catodon.*

Gray whale—*Eschrichtius glaucus.*

Right whale—*Eubalaena sieboldi.*

Minke whale—*Balaenoptera acutorostrata.*

Killer whale—*Grampus rectipinna.*

Dall porpoise—*Phocoenoides dalli.*

History

The whaling industry along Canada's western coast is served by five major species: fin, humpback, blue, sei and sperm whales. From one to four whaling stations have operated on Vancouver Island or the Queen Charlotte Islands almost every year since the first station opened in 1906. Since 1919 the catch has totalled approximately 7,000 whales in the relative proportions of 4% blue, 33% fin, 12% humpback, 8% sei and 42% sperm. At least as many whales were taken prior to 1919. Complete statistics for these are not available, but it is known that early catches contained a large proportion of humpback whales.

The following table shows the British Columbia total whale catch by species. For 1911-15 a complete breakdown by species is not available. No whaling was done in 1921, 1931, 1932, 1939 and 1944-47.

Years	No. of whales							No. of whaling stations	
	Blue	Fin	Hump	Sei	Sperm	Others	Total	Vancouver Island	Queen Charlotte Islands
1911-1915	..	..	..	..	..	..	3,805	2	2
1916-1920	78	460	227	195	102	48	2,217	1	2
1921-1925	151	520	215	222	291	8	1,507	1	2
1926-1930	97	632	88	201	538	3	1,568	...	2
1931-1935	7	108	15	1	630	..	761	..	2
1936-1940	10	232	27	2	954	..	1,225	..	2
1941-1943	2	107	41	..	432	..	582	..	2
1948-1950	6	292	286	29	137	1	751	1	..
1951-1955	55	909	302	311	1,100	23	2,710	1	..
							15,126		

Whales are pelagic and migratory animals, knowing no national boundaries. Canadian coastal waters include only a small part of their range of distribution. Evidence, based chiefly on analogy with whale stocks in other localities suggests that the whales serving the British Columbia industry are mostly transients alternating between winter breeding grounds in low latitudes and summer feeding grounds in high latitudes (Mackintosh, 1946). Some interchange between stocks in the eastern and western sectors of the North Pacific may occur, but the extent of this interchange must be determined by whale marking and racial studies. Interchange across the equator is not great. Recent evidence places the northern limit of distribution of blue and sei whales as the Aleutian Islands. No male sperms have been seen north of 62° latitude and no female sperms have been taken north of 52° latitude (Omura, 1955). Fin and humpback whales are known to penetrate through Bering Straits into the Arctic Ocean but their main feeding grounds are probably farther south, near the Aleutian Islands.

Stocks of whales in the northeast Pacific have been exploited by shore stations operating along the coast of California, Washington and Alaska as well as British Columbia, and by factory ships operating off Lower California, California and in Alaska waters (Pike, 1954). Shore stations operating in Alaska took almost 9,000 whales, mostly fin and humpback, from 1910 to 1940. A shore station on the Washington coast took almost 3,000 whales, mostly humpbacks, from 1911 to 1925. Shore stations and factory ships operating off California and Lower California took almost 6,000 whales, mostly humpback and blue, from 1919-30. In 1954 a Japanese factory expedition conducted successful trial operations in the eastern Aleutian Islands, mostly within a 200 mile radius of Dutch Harbour. The catch of 1,030 consisted of 73% fin whales.

Historical evidence of whaling in the northeast Pacific shows that, as a whole, this region has sustained a sizeable whale fishery for 50 years. Humpbacks and blue whale catches have declined rapidly wherever these species were attacked in numbers. Whaling from all stations has con-

tributed to the reduction of humpback stocks. Blue whale stocks were reduced chiefly by factory operations off California and by Alaska stations. Fin whales are distributed widely and abundantly in the northeast Pacific and appear not to have suffered greatly under the pressure of whaling. Sei whales have not been exploited heavily, relative to the other species, owing to their small size and poor yield of oil. Sperm whale stocks have not been greatly reduced because of the polygamous breeding habits of the species and the small size and limited geographical distribution of the females.

Whaling is regulated by the International Whaling Convention of 1946, the terms of which restrict the taking of certain species and female whales accompanied by calves, impose minimum length limits for each species, limit the length of the catching seasons and restrict factory operations in certain areas. The North Pacific remains open to factory ships whaling for baleen whales north of 20° latitude, except for a section between 20° and 38° latitude and east of the 150th meridian. Whaling for sperms remains open to factory ships and shore stations throughout the North Pacific. Right whales and gray whales, two species which were exploited in the North Pacific and Arctic Oceans near to extinction during the last century, are now completely protected.

Present Status

The present status of the industry is represented by the catches of the Coal Harbour whaling station, which is located on the west coast of Vancouver Island. This plant, which began operations in 1948, is the only whaling station now operating along the west coast of North America. Its fleet of 6 catcher boats took 630 whales in 1954 and 629 in 1955. These catches are taken during a six-month period from April through September, mostly within 150 miles of the station.

The Japanese catch of 1,030 whales around the eastern Aleutians in 1954 comprised 73% fin and 11% blue whales. These were taken at a rate of 2.12 fin whales and 0.32 blue whales per catcher's day's work. In British Columbia waters the take per catch day was 0.28 for fin whales and 0.02 for blue whales, in 1952-55. These figures indicate the much greater availability of these species in the Aleutian area. No attempt was made by the Japanese to take sperm whales. In British Columbia the catch of sperm whales for the years 1952 to 1955 was 2.12 per catcher's day's work. Catch per unit of effort figures for the 1954 catch of blue and fin whales in the Aleutian area are greater than corresponding figures for the Antarctic. The entire whale stock in the North Pacific is, however, probably small as compared to the Antarctic stocks but is concentrated in a smaller area.

Whales taken by the British Columbia station are of a smaller size and consist of a higher proportion of immature animals than those taken in the Aleutian area. Immature fin whales comprised 60% of the male and 50% of the female catch of fin whales in British Columbia as compared to 16% male and 13% female immature whales in the Aleutian catch. Similar differences occur in the other species. The comparison suggests age differences in the migratory pattern, but the differences may be in part a result of differences in the minimum legal length limits adhered to.

No sizeable expansion of the whaling industry in British Columbia may be expected if the industry continues to operate exclusively from a shore station. Notwithstanding the addition of one or more new stations, an event which seems unlikely, it is anticipated that only minor changes will occur in the total annual catches or their species composition. Additions to the present catching fleet of 6 vessels would be without economic advantage. Increasing the range of operations from a shore station is unsound because longer towing times encourages deterioration of the carcass and consequently reduces the value of the oil and meat. International Whaling Regulations limit the catching season to 6 months for baleen whales. Subject to annual variations in weather, which affects both feeding conditions and the availability of whales on the grounds, the future catch is expected not to deviate greatly in numbers from the 1954 and 1955 catches. However the species composition will probably change somewhat.

Under the present whaling conditions there is little prospect of important extensions in the utilization of the raw material in British Columbia. Reduction in the decomposition of the meat during the interval between catching and processing, by means of faster towing and bio-chemical treatment of the carcasses, will result in more of the raw material being used for animal food. Increasingly larger proportions of the catch are being used for mink food, for which a good market exists. Conditions in British Columbia are not very favourable for the production of whale meat for human consumption.

Fur Seals—*Callorhinus ursinus*

History

Fur seals congregate in summer to breed on three groups of islands in the North Pacific Ocean; for the remainder of the year they live at sea, migrating as far south as southern California and central Japan. The breeding colonies are on the Pribilof Islands controlled by the United States of America, and on the Commander and Robben Islands controlled by the USSR (Taylor, Fujinaga, and Wilke, 1952). A fourth colony once existed on the Kuril Islands.

Fur seals have been subjected to one period of over-exploitation during the early Russian occupation of the North Pacific, but had to a considerable degree recuperated by 1867. After the Alaska purchase, from about 1870 onwards the herds were again increasingly exploited, and by 1911 the numbers were reduced to approximately 5 per cent of the probable original peak numbers. Seals were killed both on the islands and pelagically. In 1870's and 1880's pelagic sealing was exclusively a United States and Canadian industry, and remained predominantly so till 1897, when the United States pohibited pelagic sealing by her nationals. Thereafter until 1911 pelagic sealing was carried on by Canada and Japan, who first entered the field in the 1890's. Pelagic sealing became an important factor in the sealing industry after 1885 and was the chief source of seal skins from 1890 to 1909.

In 1911, an international convention was signed by the United States of America, Russia, Japan and Great Britain (on behalf of Canada). This convention outlawed pelagic sealing except by aboriginals using native methods, and provided measures for the protection of the seal herds

(Tomasevitch, 1943). The right to regulate fully the taking of seals from a herd was given to the nation controlling the breeding island of that herd. To indemnify other nations for losses arising from the prohibition of pelagic sealing, the United States agreed to deliver to Canada and Japan 15% each of the annual take of seals from the Pribilof Islands. Russia undertook to deliver a similar percentage of the Commander Island kill to Canada and Japan. Japan, which at that time controlled the Robben Island, agreed to deliver 10% of their kill to Canada, Russia and the United States. For all herds certain minimum sizes were specified below which the above division of kills would not apply.

This convention remained in force until 1941 when it was abrogated by Japan. In 1942 a provisional agreement for continued protection of the fur seals was concluded between Canada and the United States. Under this agreement Canada received 20% of the annual take of skins from the Pribilof Islands. In late 1955, Canada, Japan, the United States, and the USSR met again to draw up a new convention for regulated exploitation of the fur seals of the North Pacific. At the time of writing no agreement has yet been announced.

The accompanying table shows for 5 year periods the average annual pelagic kill of seals by Canadian vessels from 1876 to 1910, and Canada's average annual share of the kills from each breeding colony from 1911 to 1955, together with the average pelagic kill by her aboriginals. The present kill at the Pribilofs consists only of young males, 41 to 45 inches long, and takes about 65% of that size range each year.

Present Status

The excessive sealing of the last two decades of the 19th century and the first decade of the 20th century, which led to the rapid decline of all herds, was halted by the Treaty of 1911. By this time the Pribilof herd numbered little more than 100,000 animals, the Robben Island herd about 7,200 animals and the Commander Island herd 10,000 to 15,000 animals. The Kuril herd had disappeared.

The recovery of the Pribilof and Robben herds began soon after the Treaty went into effect. Poaching was nearly eliminated and a conservative policy of killing only 3- and 4-year old males instituted. Under these conditions the Pribilof and Robben herds grew rapidly until the early 1940's, when both herds began to approach their natural growth ceiling and a state of equilibrium. The latest available figures (1955) show that the Pribilof herd numbers about 1,750,000 animals and the Robben herd about 50,000 animals. The Commander herd was not given an opportunity to recover until much later than the other two. Intensive sealing continued on and about the islands after 1911. Raiding and haphazard management prevailed as a result of the Russo-Japanese war and the Russian Revolution. Poaching went on until at least 1922 when the herd was reduced to less than 18,000 animals. Russian figures published in 1934 indicated that the Commander herd then numbered only 15,200 animals. Since that time growth has apparently been more rapid for the latest Soviet figures show that in 1955 the Commander herd numbered between 50,000 and 55,000 animals. The Russians consider that the Commander herd is still in a state of rapid growth and has not yet reached its mature population ceiling.

Canada's average annual share in the North Pacific fur seal kill from 1876 to 1955.

Period	Pelagic kill		Land kill			
	Canadian sealing vessels	Aboriginals	Pribilof Islands	Robben Island	Commander Islands	Av. Annual Total
1876-80	8,798	..	..	..	..	8,798
1881-85	13,478	..	..	..	..	13,478
1886-90	35,802	..	..	..	..	35,802
1891-95	67,104	..	..	..	..	67,104
1896-1900 ...	37,102	..	..	..	..	37,102
1901-05	18,049	..	..	..	..	18,049
1906-10	5,739	..	..	..	..	5,739
1911-15	..	815	200a	36b	..	1,051
1916-20	..	319	2,881c	33d	43e	3,276
1921-25	..	2,880	3,235	76	..	6,191
1926-30	..	2,406	4,754	157	..	7,317
1931-35	..	1,266	7,927	182	..	9,375
1936-40	..	1,300	8,758	252	..	10,310
1941-45	..	15f	12,522	..	..	12,537
1946-50	..	124	13,084	..	..	13,206
1951	..	534	12,138	..	..	12,672
1952	..	28	12,784	..	..	12,812
1953	..	54	13,334	..	..	13,388
1954	..	..g	12,776	..	..	12,776
1955	..	..	13,128	..	..	13,128

a Canada's share of Pribilof Island skins in the 1911-15 period is shown as 200 skins per year. Actually, the 1,000 skins obtained during this 5-year period were all received in 1912. Killing of fur seals on the Pribilof Islands was prohibited, except for essential food use of natives, from August 24, 1912 to August 25, 1917.

b Canada received no share in the Robben Island kill from the USSR in 1911.

c Canada received no share in 1916 (see note a).

d Canada received no share of the Robben Island kill from the USSR in 1916 and 1917.

e Canada received no share of the Commander Island kill from the USSR in 1916, 1918, and 1920.

f The low kill reflects interference due to wartime conditions.

g Surveys by the Department of Fisheries in 1954 and 1955 revealed that the Canadian coastal Indians possessed no serviceable aboriginal equipment (canoes and spears) suitable for taking fur seals.

Sea Otter—*Enhydra lutris*

History

The sea otter is one of the two marine fur-bearers of the Pacific coast. Unlike the fur seal, it does not perform long migrations, and its food consists of molluscs and crustaceans taken on the sea bottom.

Unrestrained hunting by pelagic sealers in the late 19th century and the first decade of the 20th century exterminated sea otters in British Columbia and almost exterminated them in Alaska. The Treaty of 1911 for the conservation of fur seals and sea otters signed by Russia, Japan, the United States of America and Great Britain (for Canada) prohibited completely the taking of sea otters. The following table shows the average number of sea otter skins per year taken by Canadian vessels in waters off British Columbia, Alaska and probably also Siberia. The first year for which statistics are available is 1879.

Years included	Av. no. of skins	Av. price per skin
1879-1881	98	$ 40
1882, 1883, 1885, 1886	97	$ 53
1887-1890	98	$ 84
1892-1896	16	$120
1897, 1898, 1900, 1901	28	$325
1902, 1904, 1906	10	$437
1907, 1911	21	$552

The average catch declined suddenly about 1891, probably as a result of the temporary agreements of 1891 and 1892 which prohibited pelagic sealing in the Bering Sea, and of the Paris Tribunal of 1893 which prohibited pelagic sealing and sea otter hunting in the Bering Sea within the 3-mile limit and within 60 miles of the Pribilof Islands. The largest catch of 170 skins was reported in 1882 and the smallest of 7 skins in 1904 and 1911 (Scheffer, 1951). The price per skin rose to a high of $800 in 1911.

The catches above, however, give no idea of the original abundance of the sea otter, for by 1879 it had already been subjected to more than 50 years of unrestricted utilization, and relatively few survived.

Present Status

The only known colonies of sea otters in North America are (1) several hundred individuals off California; and (2) several thousand individuals on Amchitka Island in the Aleutian chain. No colonies are known to survive in Canadian waters.

The colony on Amchitka Island is being studied intensively by the United States Fish and Wildlife Service to determine whether sea otters can be transplanted to other regions, how this should be done and what type of locality is most suitable; similar experiments have been or are being tried in the USSR. Whether or not sea otters could be successfully introduced into Canadian waters will probably depend upon the results of these studies.

Sea-Lions—*Eumetopias jubata*

History

Steller sea lions are large animals, males reaching more than a ton in weight. They range along the entire British Columbia coast, and congregate to breed on a number of rocky islands offshore (Newcombe, Greenwood, and Fraser, 1918). This species has no history of extensive utilization and at present is of minor commercial value as a source of mink food. Small attempts at utilization for this purpose were made in 1952, 1953 and 1954 when 3, 14 and 4 tons of meat were landed, respectively. About 1915, one manufacturer used the hides for making gloves, boots and mocassins. He found them to be fine-grained, pliable and water resistant.

The sea lion is a nuisance to fishermen by damaging nets and feeding on fish in the nets and on trolls. Accordingly attempts have been made to reduce the size of breeding colonies near important fishing areas. The average number reported killed per year is as follows (for some years data are not available):

Years	Av. no. killed	Years	Av. no. killed
1915	2,875	1940-44	125
1922-26	1,919	1945-49	268
1927-30	1,308	1950-51	329
1935-39	2,202		

Present Status

At the present time there is little information on sea lions in British Columbia waters. An investigation is planned for 1956 aimed at improving knowledge of their food and population dynamics. Observations made on one colony of 3,000-4,000 animals in 1953 showed that about 70% were females, 10% harem males, and 20% idle males, either young or past their prime. Harems mostly contained from 1 to 14 cows.

Three censuses have been reported, as follows:

Year	Agency	Estimate	Remarks
1913	B.C. Fisheries Dept.	11,000	One large and several small colonies overlooked.
1938	Canada Fisheries Dept.	14,000	
1955	Canada Fisheries Dept.	9,000	

These figures do not include animals which are not hauled out on the rocks at the time of the census.

Seaweeds

Large kelps—*Macrocystis* and *Nereocystis.*

Small kelps—*Laminaria, Alaria, Hedophyllum, etc.*

Red algae—*Gracilaria,* etc.

Kelps are a source of algin, while red algae supply agaragar. Preliminary surveys of the abundance of kelps in British Columbia waters have revealed large quantities of *Macrocystis* and *Nereocystis* (Scagel, 1947; Neave, Hart and Quayle, 1949). It has been estimated that 1,000,000 tons of the large kelps and 500,000 tons of the small kelps exist in British Columbia waters.

Less information is available on the abundance of agar-producing plants, but it is known to be considerable. At present there is little utilization of either type in British Columbia.

The seaweeds are a marine resource of great potential importance. Agar and algin have numerous industrial uses. Exploitation of our stocks will be possible if demand increases or if improved processing methods are discovered.

Introduction of New Species in British Columbia Waters

Occasional successful transplantation of marine organisms here and in other parts of the world have stimulated interest in other possibilities. The two significant imports which we have today are the Pacific oyster and the Manila clam, both introduced from Japan (the clam accidentally). Though these two may to some extent have suppressed the native oyster and native little-neck clam, respectively, there has been a net gain in both cases because of the greater abundance and adaptability of the newcomers.

As far as fish are concerned, the north Pacific has already by far the richest fauna of any temperate region of the earth, so that it is difficult or impossible to propose any species that would fill an ecological gap and

which would be unlikely to damage native species. The Atlantic shad occurs sparingly in our large rivers, having moved north after successful introductions in California (Neave, 1954). Unlike nearly all other temperate parts of the world, the eastern shore of the North Pacific has no freshwater eels, but this omission is one that we are anxious to maintain, because of their possible predation on salmon and trout. Atlantic salmon have been proposed for British Columbia, mainly as a basis for summer freshwater angling, but they would have difficulty in establishing themselves in the face of competition from the numerous native salmonids, especially coho salmon, steelhead and cutthroat trout. Transplantations to date have failed.

The only obvious weakness in the actual and potential fisheries picture of British Columbia is the relative unimportance of crustaceans, as compared with eastern Canada and other parts of the world. The Pacific crab supports a minor though important fishery, but we miss the king crabs to the north and the spiny lobsters to the south. Two kinds of animals have been proposed to augment this branch of the industry; the eastern lobster, *Homarus americanus,* and a spiny lobster, *Jasus lalandei.*

Lobsters: The eastern lobster is the more familiar of these and seems to offer greater opportunities. There is little likelihood that it would ever become as abundant as in eastern Canada, because much of the Pacific coast lacks the shelving coastal underwater terrain which makes good lobster ground; nevertheless, there are considerable areas which seem suitable.

It has been shown that adult lobsters survive well in enclosures in the Strait of Georgia, but no survival of larvae has been observed, possibly because of periodic low surface salinity in late spring and summer. Following three earlier failures in 1898-1909, the possibilities of this area were again tested, by a large-scale introduction to Lasqueti Island in 1946, with negative results. Females were observed carrying eggs a year later but no young lobsters were ever found. Any future trials should probably be in a region less affected by river run-off, such as the west coast of Vancouver Island or somewhere in the Queen Charlotte Islands area. There is as yet no reason to presume that success is impossible, though it seems clear that it will not come easily.

Lobsters do not favor the sandy bottom preferred by our Pacific crab, so little competition between the two would be likely.

Spiny lobster or crayfish. The native spiny "lobster" of the North American coast *(Panulirus)* is abundant in southern California, but does not range north to British Columbia. In the southern hemisphere a species of the related genus *Jasus* supports a large fishery in temperate waters. (Most species occur in warm water). This might prove adaptable to our conditions. Though it would be unlikely to support any really large fishery here, catches of the same order as the present crab fishery might be possible. Spiny lobsters tend to frequent rocky coasts.

Summary

The following table includes estimates of the sizes of the basic stocks exploited by British Columbia's fisheries and of the average annual catches provided by those stocks (both in millions of pounds unless otherwise stated). Some species or groups of species are listed without data. These

include stocks which no longer support fisheries and those which may support fisheries in the future. Dashes indicate cases where lack of information prevents reasonable estimation.

	Present stock	Utilization Canada	Others	Total
SALMON	411.6	180.2	..	..
Sockeye salmon	83.6	41.2	16.0	57.2
1. Fraser River	42.0	17.0	16.0	33.0
2. Skeena River	14.0	7.0	0.0	7.0
3. Nass River	2.6	1.6	0.0	1.6
4. Rivers Inlet	12.3	8.0	0.0	8.0
5. Smith Inlet	2.7	2.0	0.0	2.0
6. Other Areas	10.0	5.6	0.0	5.6
Pink Salmon	116.0	45.0	13.0	58.0
Chum Salmon	150.0	58.0	23.0	81.0
Coho Salmon	40.0	23.0	..	..
Spring Salmon	22.0	13.0	..	..
STEELHEAD	5.0	0.6[1]	..	..
HERRING	790.0	380.0	0.0	380.0
PACIFIC HALIBUT	445.0	28.0	43.0	71.0
GROUNDFISH	1,012.0	28.3	30.1	58.4
Lemon Sole	15.0	2.8	1.3	4.1
Brill	15.0	1.5	3.5	5.0
Rock Sole	40.0	3.2	0.5	3.7
Butter Sole	25.0	1.0	0.0	1.0
Dover Sole	40.0	0.7	0.6	1.3
Gray Cod	53.0	4.6	6.2	10.8
Lingcod	120.0	3.9	2.3	6.2
Rockfish (10 spp.)	30.0	0.9	8.1	9.0
Blackcod	14.0	1.3	2.7	4.0
Other trawl species	20.0	0.7	0.9	1.6
Scrapfish (10 spp.)	40.0	2.4	1.0	3.4
Dogfish	600.0	5.3[2]	3.0[2]	8.3[2]
SHARKS OTHER THAN DOGFISH	..	0.0	.	..
SMELTS	..	0.4	..	..
TUNA	..	0.0	..	..
PILCHARD	..	0.0	..	..
ANCHOVY	25.0	0.2	..	..
MISC. PELAGIC SPECIES (e.g. Saury)	..	0.0	..	..
CRABS	7.5	3.7	1.2	4.9
SHRIMPS AND PRAWNS	5.0	1.1	0.0	1.1
MOLLUSCS				
Pacific Oyster	cultured	80,000 U.S. gal.	0.0	90,000 U.S. gal.
Butter clam	20.0	3.5	0.0	3.5
Razor Clam	..	0.2	0.0	0.2
Little-neck clam	3.0	0.8	0.0	0.8

	Present stock	Utilization Canada	Others	Total
Other Molluscs (e.g. Squid)	..	0.0	..	0.0
Whales	..	610 whales	..	610 whales
Fur Seals	1,855,000 seals	13,100 seals	58,400 seals	71,500 seals
Sea Otters	0.0	0.0	0.0	0.0
Sea Lions	12,500 sea lions	90-100 sea lions	..	..
Seaweeds	3,000.0	0.0	..	..

1 An additional 650,000 lb. are estimated to be taken annually in subsistence and sport fisheries.

2 Utilization expressed in terms of weight of whole fish caught, although only the livers are landed.

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Effect of Ship's Roll on the Ekman Current Meter

Susumu Tabata and A. W. Groll

Abstract—Tests were made with a pair of Ekman current meters to observe the effect of ship's roll upon their measurements and their behavior. In calm seaways where the current speed ranged from five to 45 cm/sec the speeds indicated by the two instruments were consistent within five per cent, and the indicated directions were within four degrees. In weaker currents the direction difference is twice as large. When the sea/swell conditions became greater than 1/1 the scatter in the indicated speeds became greater than ten per cent, and the results were considered unusable. Directions were measured within an accuracy of ten degrees in sea/swell as great as 2/3. One instrument was given an oscillation approximating a movement caused by a ship's roll of 10 to 15°. Its recorded speeds were 1.5 times those measured by a stationary one. This increase is due to the excess revolutions made by the propeller of the oscillating instrument during its downward swing. The increase in the scatter of the speed differences of the two instruments during sea/swell >1/1 is attributed to this also. There was no appreciable variation in the directions during this artificial roll except when measurements were made in weak currents.

Introduction—The Ekman current meter is widely used to observe ocean currents because of its relatively low cost, its simplicity and ruggedness of construction, and the reliability of its measurements when used in calm seas. The Pacific Oceanographic Group has used this instrument extensively in the study of the coastal currents of British Columbia. However, from time to time measurements have been made from anchored ships that rolled in the seaway. Under such conditions the measurements obtained were considered doubtful.

Since the effect of the ship's roll upon these measurements and also upon the behavior of the instrument was not too well known, series of tests were made to observe this. These tests were made by employing a pair of Ekman current meters in the following experiments: (1) simultaneous measurements from a rolling ship in a rough seaway; (2) simultaneous measurements from a steady ship in a calm seaway; (3) simultaneous measurements during an artificial ship's roll in which one instrument was given an oscillation simulating a motion caused by a ship's roll while the other was kept stationary; and (4) direct underwater observation of the behavior of the instruments during Experiment (3).

The Ekman current meter was designed by *Ekman* [1905] and has since been improved [1932]. The instrument records the number of revolutions made by an eight-blade propeller during an arbitrary time interval. A calibration curve is used to relate these data to the current speed. The current directions are indicated by small metal balls which are released at intervals and are directed by a magnetic compass into one or more of the 36 individual compartments in a radially divided compass box. During measurements, the instrument is lowered over the side of the ship from a wire line whose end is fastened to a swivel mounted on its top, so that it can swing freely about its vertical axis. A lead weight suspended a few meters below the instrument keeps it steady and upright. It is started and stopped by a trigger mechanism that is actuated by the impacts made by the messenger weights despatched along the wire which suspends it.

The ship used for the tests was the Royal Canadian Naval Research Vessel, HMCS *Cedarwood*, a wooden ship of length 51 m (167 ft), beam 9.2 m (30 ft) and draft 4.5 m (15 ft). She has a natural rolling period of 4.5 sec. The booms from which the instruments were suspended were located slightly forward of amidship and 5.5 m (18 ft) outboard of the centerline. Observations were made while the ship was anchored from the bow with the scope (ratio of length of anchor cable out to depth) as small as practicable to reduce ship movement.

In the analysis of the data, no attempt is made to account for the possible deviations in the compass headings of the instruments caused by the magnetism of the ship, as these were considered negligible.

Experiment (1), Simultaneous measurements from a rolling ship—The first test of the series was conducted in a rough sea to compare the measurements obtained by the two instruments under variable rolls of the ship. It was carried out during a routine current survey in Hecate Strait at locations where the depths were greater than 80 m. During this test the sea/swell condi-

TABLE 1 – *The Beaufort scale*

Beaufort scale	Wave height
	ft
0	0
1	Less than 1
2	1 to 3
3	3 to 5

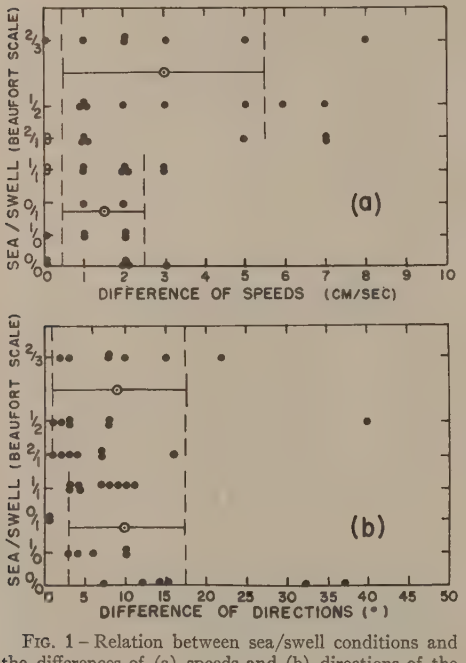

FIG. 1 – Relation between sea/swell conditions and the differences of (a) speeds and (b) directions of the two Ekman current meters; dashed lines are those limits set by ± standard deviations

tions varied from 0/0 to 2/3 on the Beaufort scale (see Table 1) creating a roll up to 20°. The two instruments were suspended on the opposite sides of the ship. They were placed at depths between 10 and 50 m and were allowed to run for periods of two or three minutes.

Figure 1 shows the relationship of the differences of (a) the speeds and (b) the directions of the two instruments with various sea/swell conditions. The observed speeds ranged from 15 to 55 cm/sec with an average of 30 cm/sec. Analysis of the data showed that there was no correlation of the differences with current speed. The apparent error at low speeds was no greater than at high speeds; hence the difference is assumed to be a function of oscillation alone. The difference of the recorded speeds doubled from 1.5 to 3.0 cm/sec when the sea/swell increased from $\leq 1/1$ to $>1/1$ and was accompanied by a proportional increase in the scatter. There was, however, no appreciable change in the differences of recorded directions with sea/swell conditions. These differences were generally within ten degrees during sea/swell from 0/0 to 2/3.

Experiment (2), Simultaneous measurements from a steady ship—This test was made to determine the limits of the reliability of the instruments. During this and the succeeding experiments, the ship was anchored in 70 m; the sea was calm. The two instruments were suspended from the two booms on the same side of the ship with a fore-and-aft separation of about 1.5 m, which was sufficient to eliminate interaction between their compass magnets. The current flowed obliquely to the length of the ship so that one meter was not in the stream of the other. They were lowered to ten meters and, as before, allowed to run for periods of two or three minutes.

The differences between the recorded speeds increased with increasing current speeds as shown in Figure 2. These differences, which amounted to five per cent, were approximately proportional to the recorded speed. The differences in directions were generally within four degrees, but in weak currents they reached values as large as ten degrees.

Experiment 3, Simultaneous measurements during an artificial roll of the ship—This test was conducted to determine the effect of an artificial roll of 10° to 15° of the ship on the meter readings.

One instrument was held stationary at a depth of seven meters while the moving one was placed so that it oscillated about the seven meters depth. The instruments were allowed to run for periods of two or three minutes. In order to simulate the ship's roll of 10° to 15°, it was necessary to give the moving instrument a vertical displacement of 1.8 to 2.8 m and a horizontal displacement of 0.2 to 0.4 m. In practice, however, it was given a vertical displacement of about two meters by one observer working the winch and a horizontal displacement of about 0.5 m by another observer pushing the wire back and forth from the platform (chains). The periods of these oscillations varied from 4.2 to 4.8 sec. The method used here in creating the motion caused by an artificial roll may not be an accurate reproduction of the ship's roll in the sea where irregular rolling occurs, but it is assumed that it can be used to first approximation.

Table 2 shows the speeds and directions recorded by the stationary and oscillating instruments. Observations made when the current

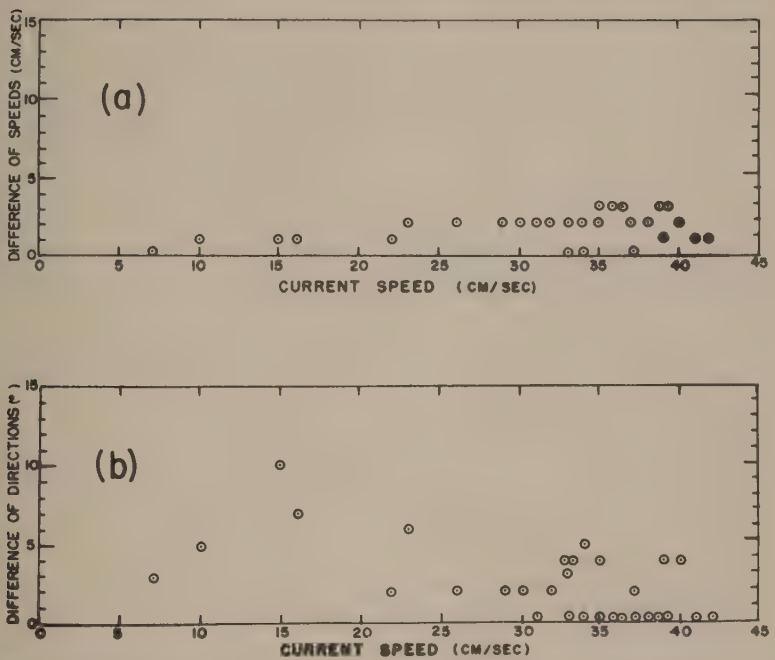

FIG. 2 – Differences of current (a) speeds and (b) directions between the two Ekman current meters placed at a depth of ten meters and observed from a steady ship

TABLE 2 – *Current speeds and directions recorded by moving and stationary Ekman current meters; current speeds greater than 20 cm/sec*

Trials	Stationary speed	Instrument direction	Moving speed	Instrument direction	Differences	
					Speed	Direction
	cm/sec	°	cm/sec	°	cm/sec	°
1	28	280	44	286	16	+6
2	28	276	44	274	16	−2
3	25	276	37	274	12	−2
4	30	278	44	274	14	−4
5	26	274	43	279	17	−5
6	29	270	42	269	13	−1
7	24	274	40	278	16	+4
8	24	279	39	272	15	−7
9	22	284	34	280	12	−4
10	29	274	50	273	21	−1
Mean	26	276	42	276	15	4

speeds ranged from 20 to 30 cm/sec (recorded by stationary instrument) demonstrated that the oscillating instrument recorded speeds that were greater than 1.5 times those of the stationary one. There was, however, no appreciable difference in the direction; in fact, the mean difference

TABLE 3 – *Current speeds and directions recorded by moving and stationary Ekman current meters; current speeds less than 10 cm/sec*

Trials	Stationary speed	Instrument direction	Moving speed	Instrument direction
	cm/sec	°	cm/sec	°
1	10	296	11	326
2	5	...	3	326
3	6	336	20	121
4	9	356	20	114
5	5	016	13	043
6	8.	016	8	016
Mean	7	...	12	

only amounted to four degrees. When the currents were weaker (<10 cm/sec) the recorded speed of the oscillating instrument was again much larger, but in this case wide variations in directions occurred, as shown in Table 3.

Experiment (4), Direct underwater observations of the behavior of instruments during Experiment (3)—Direct underwater observations of the instruments during Experiment 3 were accomplished by a team of aqualung divers who examined the action and behavior of both the oscil-

lating and the stationary instruments. Their description is of interest:

"Both instruments lined up with the current directions when they were activiated by the messengers. The propeller of the stationary instrument rotated unit formly, and its direction remained fairly constanduring the recording intervals. The action of the moving instrument was quite different. While making its vertical movements it oscillated through an arc of approximately five degrees on either side of the current direction indicated by the stationary one. When ascending it decelerated and came to a full stop $\frac{1}{2}$ to $\frac{1}{3}$ m before the top of the upward swing. As soon as the downswing commenced, it started to rotate again, and accelerated markedly. The accelerations, however, were not constant; occasionally near the start of the downswing the propeller would start to rotate, then stop, and start again. The accelerations and decelerations of the propeller were rapid. It appeared to be rotating much faster than the propeller of the stationary meter for about 75 per cent of the cycle."

Discussion—Simultaneous current measurements made by a pair of Ekman current meters from a steady ship in a calm seaway where the current speeds ranged from five to 45 cm/sec (Experiment 2) showed that the recorded speeds agreed within five per cent and the directions within four degrees. In weaker currents (less than 15 cm/sec) the disagreement in directions was about twice as large. These limits define the reliability of the instruments.

During sea/swell $\leq 1/1$ when the ship's roll was small (Experiment 1) the differences in the recorded speeds were the same as those measured from a steady ship whereas the differences in directions were about twice as large (ten degrees compared to four degrees). However, as soon as sea/swell of 1/2 or 2/1 was reached, accompanied by an increase in the ship's roll, the disagreements in speed doubled from five to ten per cent while those of the directions remained unchanged. The implication here is that the random behavior of the instruments causes these variations that increase with increasing sea/swell conditions. It is likely that the recorded speeds are trustworthy when sea/swell conditions are $\leq 1/1$ but too high when they are $>1/1$. The directions, however, appear reliable (within ten degrees) to sea/swell as large as 2/3.

The test designed to determine the effect of an artificial roll of the ship (Experiment 3) on current measurements clearly demonstrated that large errors in current speeds are introduced when the instrument is undergoing regular and rapid oscillations. However, the current directions do not seem to be affected appreciably except perhaps when the measurements are made in weak currents (10 cm/sec).

These large variations in the speed are no doubt due to the erratic revolutions of the propeller (Experiment 4), which rotates excessively during the downswing of the oscillating instrument. The increase in the scatter of the differences of recorded speed during sea/swell $>1/1$ (Experiment 1) is also attributed to its erratic behavior during its oscillation.

It is quite apparent from these tests that the ship's roll has a large influence on the current measurements. Therefore, when currents are measured from a rolling ship, the recorded speeds under all conditions and the recorded directions for weak currents are questionable.

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Quality of Sardines (Clupea pilchardus Walb.) Held Unfrozen and Frozen Prior to Canning

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An objective study, begun in 1953 *(18)*, has been made of the effects of refrigerated storage on the quality of Yugoslav sardines (*Clupea pilchardus* Walb., the true sardine) immediately prior to canning and throughout a shelf life of the canned product of about 1½ years. The sardines were caught in the months of June, July and August.

Several reports of work with unfrozen and frozen herring used for fresh, frozen, smoked and canned products *(3, 4, 5, 6, 8, 11, 20, 21, 22, 23)* and with the chilling and freezing and subsequent storage of sardines and similar fish *(10, 14, 15, 16)*, are given in the

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literature. A publication from France *(17)* without experimental data, states that stored frozen sardines produced canned fish of variable quality. In Norway, sprats have been held successfully at temperatures of —16.6° F. (—27° C.) and —31° F. (—35° C.) for a few weeks prior to canning and smoking *(1)*.

A pre-canning keeping time of California pilchards at a temperature of 35° to 40° F. (1.7° to 4.4° C.) of at least 5 days has been suggested *(10)*. In commercial practice, most of these fish are not iced or otherwise refrigerated at sea. They are landed about 12 hours after catching and must be processed within about 4 or 5 hours *(9)*. The canners estimate that brine chilling at sea might extend the packing time to possibly 12 hours *(9)*. The different appraisals of the keeping time may be found in the use in the former case of chemical data as an index of the condition of the fish and in the latter case of the results of organoleptic examination. As shown below, organoleptic examination of sardines, both before and after canning, is considered to offer a fairly reliable index of the suitability of the fish for canning. Chemical tests are considered to act only in a supporting role. The former showed that the longest possible keeping time for unfrozen sardines in ice at a temperature of 30° to 31° F. (—1.1° to —0.5° C.) was 3 days and for frozen sardines in —4° F. (—20° C.) storage, it was about 1 month.

EXPERIMENTAL

Pertinent data concerning the treatment of the fish of 6 catches used in the experiments are given in Table 1. It was impossible to obtain all samples of commercially-caught fish from any one fishing port, hence the differences in the mode and time of transportation for the various lots. All fish, however, were caught in the same area of the North Adriatic Sea.

Prior to canning, the fresh chilled fish, the stored unfrozen fish, and the fish thawed after removal from frozen storage were examined organoleptically and peroxide determinations were made in the laboratory of the Rijeka Hygiene Institute.

The following tests of canned fish were done at the Chemical Laboratory of the Rijeka Hygiene Institute, and at the Fish Inspection Laboratory, Halifax: (a) organoleptic examination; (b) determination of peroxide value; (c) determination of free fatty acids; (d) determination of salt.

Daily, over a period which varied from 7 to 10 days, a sub-lot, usually a case or wooden box containing about 27 lb. (12 kg.) of fish, was drawn from each lot of stored unfrozen sar-

TABLE 1

Handling and storage conditions for Yugoslav sardines

Catch No.	Lot No.	Elapsed time in hours—catching to cold store	Average temperature of sardines upon arrival at cold store	Method used at cold store to complete chilling or to freeze sardines	Conditions of storage	No. of sub-lots canned
I	1	12		A	F	10
I	2	12		A	E	10
II	3	15		B	E	10
II	4	15	42° F. (5.5° C.)	B	F	8
II	5	15		C	H	5
II	6	15		D	G	5
II	7	15		D	H	5
III	8	32		C	H	5
III	9	32	37.4° F. (3° C.)	D	G	5
III	10	32		D	H	5
IV	11	12		B	E	9
IV	12	12		B	F	8
IV	13	12		A	E	10
IV	14	12	38.3° F. (3.5° C.)	C	H	4
IV	15	12		D	G	4
IV	16	12		D	H	4
V	17	12	42° F. (5.5° C.)	B	E	9
VI	18	15		A	E	9
VI	19	15		A	E	9
VI	20	15		A	E	9
VI	21	15	53° F. (11.7° C.)	A	E	9
VI	22	15		A	E	8
VI	23	15		A	E	9
VI	24	15		A	E	9

Handling from Sea to Cold Store

Catch No.

I (Lots 1, 2)—Uneviscerated, iced in cases within 2 hr. of catching. Boat journey of 10 hr.

II (Lots 3, 4, 5, 6, 7)—Uneviscerated, iced in cases within 3 hr. of catching. Boat journey of 12 hr.

III (Lots 8, 9, 10)—Uneviscerated, iced in cases within 9 hr. of catching. Boat journey of 20 hr.

IV (Lots 11, 12, 13, 14, 15, 16)—Uneviscerated, iced in cases at catching and again 5 hr. later. Boat journey of 10 hr.

V (Lot 17)—Uneviscerated, stowed in cases without ice at sea. Placed in unagitated refrigerated sea water 4 hr. later. Boat and truck journey of 5½ hr.

VI (Lot 18)—Uneviscerated, iced in cases at catching. Boat and truck journey of 5½ hr.

VI (Lot 19)—Uneviscerated, iced in cases at catching. Eviscerated, washed and re-iced 6 hr. later. Boat and truck journey of 5½ hr.

VI (Lot 20)—Uneviscerated, stowed in cases without ice at sea. Iced in cases 6 hr. after catching. Boat and truck journey of 5½ hr.

VI (Lot 21)—Same treatment as Lot 20, but eviscerated before icing.

VI (Lot 22)—Uneviscerated, stowed in cases without ice at sea. Iced in cases 8 hr. after catching. Boat and truck journey of 5½ hr.

VI (Lot 23)—Same treatment as Lot 22, but eviscerated before icing.

VI (Lot 24)—Uneviscerated, salt but not ice added to fish in cases at sea. Sardines washed and iced 8 hr. after catching. Boat and truck journey of 5½ hr.

Code for Method Used at Cold Storage

A—Refrigerated in ice and still air at 30 to 31° F. (—1.1 to —0.5° C.).

B—Unagitated, constantly refrigerated sea water at temperature of 28° F. (- 2.2° C.).

C—Unagitated, constantly refrigerated eutectic brine at temperature of —4° F. (—20° C.).

D—Air blast of 1400 ft./min. (7 m./sec.) velocity, refrigerated to 1.5° F. (—17° C.) at start and to 4° F. (20° C.) at completion of freezing.

Code for Conditions of Storage

E—Top layer of boxed unfrozen sardines buried in ice. Storage room temperature 30 to 31° F. (—1.1 to —0.5° C.).

F—Top layer of boxed unfrozen sardines exposed to air. Storage room temperature 30 to 31° F. (—1.1 to —0.5° C.).

G—Blocks of glazed, frozen sardines stored at temperature of —4° F. (—20° C.).

H—Blocks of unglazed, frozen sardines stored at temperature of —4° F. (—20° C.).

dines. About 2 lb. (1 kg.) of the fish was used for organoleptic and chemical tests while the remaining fish were canned. The same procedure was followed for the frozen fish except that withdrawals were made at intervals of 3 to 6 weeks. Frozen fish were defrosted in clean fresh water (maximum immersion time, 1 hour) at a temperature of about 59° F. (15° C.). Both the sardines unfrozen since catching and those recently thawed were beheaded and eviscerated by hand, brined for 30 minutes in 25% brine, dried on wire racks for about 3 hours in the sun, fried in olive oil at 230° to 248° F. (110° to 120° C.) for 7 to 8 minutes, drained, and packed. Pure olive oil was added to the cans and the tins were closed and processed 2¼ hours in boiling water at 212° F. (100° C.). About 50 cans (¼ club) were obtained from each sub-lot of fish. All canning operations were performed by regular factory personnel.

Organoleptic examination of the fish prior to canning was carried out by a panel of three. The following aspects of the fish were examined: condition of skin and eyes, color and odor of gills, odor of whole fish, texture of whole fish, condition of bellies after beheading and evisceration, color of flesh near the severed head and in the filleted fish—both within and without the lateral band of dark muscle—and odor and firmness of the filleted fish. The forms used in these examinations listed several obvious stages of degradation for each feature under study. For each aspect the panel decided the number of days of storage permitted; that is, the number of days during which the fish were acceptable.

The Wheeler test for peroxide *(24)* was performed on the fish of the first two catches prior to canning. The beheaded, eviscerated, scaled fish were homogenized. A quantity of 10 g. of the homogenized material was placed in a shaking funnel, desiccated by alkali-free anhydrous sodium sulphate and the fat extracted for 1 hour with 100 ml. low boiling petroleum ether. Twenty ml. of the extract was evaporated to determine fat content and another 20 ml. was used to determine peroxide oxygen. For the latter 50 ml. of fresh solution of 6:4 acetic acid-chloroform containing 1 ml. saturated solution of potassium iodide was added, followed by 100 ml. of 0.05% starch. The iodine liberated was titrated with 0.01 N-thiosulphate solution. A blank test was run under the same conditions. Results are expressed as ml. 0.01 N-thiosulphate per 1 g. of fat.

A modification of the Lea method *(7)* was employed in determining the peroxide number for all sub-lots of fish from Catches III, IV, V, and VI. To 20 ml. extract obtained as above, 20 ml. 2:1 acetic acid-chloroform solution and 2 drops of saturated potassium iodide solution were added. The whole was left in the dark for 10 minutes. The iodine liberated by addition of 15 ml. of 15% solution of potassium iodide was titrated with 0.002 N-thiosulphate solution. Results are given in ml. 0.002 N-thiosulphate per 1 g. of fat.

Examination of the canned fish was carried out by a panel of three according to standard procedures used at the Fish Inspection Laboratory, Halifax. Among the features looked for

in the examination were broken fish, broken bellies, torn skin; and odor, flavor, saltiness, and color of the fish flesh. The fish were considered acceptable if a very good standard quality or better product was obtained.

All chemical tests on the canned fish, other than that for salt content, were made in the Rijeka Hygiene Institute Laboratory. Salt content in the fish after draining was determined at the above institution, and in the Fish Inspection Laboratory, Halifax, by the Volhard method *(2)*.

Peroxide determinations on the canned fish were made by the modified Lea method *(7)*.

Free fatty acid determinations for the canned fish were made as follows: to 5 g. oil were added 20 ml. solution 1:1 alcohol: ether, and the mixture was titrated with 0.1 N-sodium hydroxide solution. The results are given in ml. N-sodium hydroxide for 100 g. oil.

RESULTS

Organoleptic examination

Unfrozen Sardines. When examined prior to canning, the fish iced at sea and held uneviscerated in ice ashore were much superior to fish of the same catch iced at later periods, as determined by resistance to (a) reddening on the outside of the head (b) discoloration of the gills (c) development of odors on the outside, in the gills, and on the fillet of the fish and (d) development of broken bellies (Lot 18 vs. Lots 20, 22, Table 2). As judged by all factors with the exception of condition of the eyes, and odor of the viscera, the fish iced at sea and held uneviscerated ashore had a storage life in the unfrozen state of about 3 days. The fish which were not iced until landing or later were not stored because of broken bellies. Examination of the canned fish showed that the sardines iced at sea and held uneviscerated 3 days after catching were acceptable as raw material for canning.

The results of the organoleptic examination of two lots of fish iced at sea (Lots 13 and 18) show some variation. Lot 18 was inferior in texture which is attributed to a combination of the effects of slower cooling and the severity of jolting in the truck journey. Lot 13 was cooled more efficiently because of the extra icing 5 hours after capture. The color and odor of the outside of the head and the gills of the fish from Lot 13 were judged to deteriorate more rapidly than for Lot 18. This was not reflected in the condition of the fish flesh which, on the average, was in the same state of preservation for the two lots after equal periods of storage.

Icing at sea or at later periods did not result in significant differences in the quality of the eviscerated fish appraised prior to canning (Lots 19, 21, 23, Table 2). The sardines had a storage life of 2 days and, if odors were omitted from consideration, a storage life of 3 days. Examination of the canned fish proved to be more selective, the fish iced at sea being always equal to or better than fish iced later with respect to broken bellies, color, texture, and flavor. The latter examination showed all sub-lots to be acceptable as raw material for canning on the

TABLE 2

Permissible storage (days) for unfrozen sardines based on organoleptic examination of the fish before canning (Lot No. corresponds to Lot No. given in Table 1)

Lot No.	Treatment of sardines	Eyes	Skin	Color			Odor				Texture		Broken	
				Outside of head	Gills	Fillet	Exterior	Gills	Viscera	Fillet	Whole fish	Fillet	Fish	Bellies
11	Uneviscerated, iced at sea and partly chilled. Chilled in refrigerated sea water ashore to about 28° F. (—2.2° C.) and stored in ice in 30 to 31° F. (—1.1 to —0.5° C.) room.	2	7	2	2	5 6	2	2	6	6	7	7	7+	2
12	Same as Lot 11, except fish stowed without ice in 30 to 31° F. (—1.1 to —0.5° C.) room.	2	7+	2	2	5 6	3	3	3	3	7+	7	7+	2
13	Uneviscerated, iced at sea and re-iced at 5 hours. Chilled in ice in 30 to 31° F. (- 1.1 to —0.5° C.) room and stored therein.	2	7+	2	2	5–6	2	2	2–3	3–6	7+	6–7+	7+	2–3
17	Uneviscerated. Not iced at sea. Chilled in refrigerated sea water ashore to 28° F. (—2.2° C.) and stored in ice in 30 to 31° F. (—1.1 to —0.5° C.) room.	1–2	4	1	1–2	5–6	1	0	2	2	5	4	7	0

18	Same as Lot 13 except not re-iced.	1–2	7+	2–5	4–5	6	4	4	2	5	4–5	6	7+	3–4
19	Same as Lot 18, except that fish eviscerated and washed before icing and storage in 30 to 31° F. (—1.1 to —0.5° C.) room.	.	7+	....	.. .	5·6	1	....	....	2	7+	5–6	7+	6
20	Uneviscerated, not iced at sea. Chilled in ice in 30 to 31° F. (1.1 to —0.5° C.) room and stored therein.	1–2	7+	1	3 4	5–6	3	1	2	2	5-6	4 5	7+	0
21	Same as Lot 20, except fish were eviscerated and washed before icing and storage in 30 to 31° F. (—1.1 to —0.5° C.) room.	. .	7+	....	....	5–6	1	....	1	1	7	4	7+	2 4
22	Same as Lot 20, except an additional 2 hr. delay before icing was permitted.	1 2	7+	1	4	5 6	1	1	2	3	5–6	4–5	7+	0
23	Same as Lot 22, except fish were eviscerated and washed before icing and storage in 30 to 31° F. (—1.1 to —0.5° C.) room.	....	7+	....	....	5–6	2	....	....	2	5 6	5–6	6 7	3–4
24	Uneviscerated, salted but not iced at sea. Chilled ashore in ice in 30 to 31° F. (—1.1 to —0.5° C.) room and stored therein.	0	7+	0	3–4	4–5	3–4	0	1	1	7+	6	6-7	3–4

+ sign is used where permissible storage time was greater than 7 days.

day of catching. For the fish stored until the third day after catching, only those which had been iced at sea and some of those iced immediately upon landing were acceptable.

Prior to canning, eviscerated fish showed greater odor development than uneviscerated fish (Lot 19 vs. Lot 18, Table 2), probably due to the exposure of large surface areas to contact with air, but the former suffered fewer broken bellies than the latter (Lots 19, 21, 23 vs. Lots 18, 20, 22, Table 2). The instances where broken bellies prevented storage (Table 2, Lots 17, 20, 22) reflect on the practice of delaying the application of refrigeration too long and possibly indicate rough handling. Little overall difference in quality was evident between eviscerated and uneviscerated fish in storage when both were iced at sea however, as determined prior to canning (Lots 19 and 18, Table 2) and after canning. The latter examination showed that fish were acceptable during 3 days of storage but not thereafter.

No significant difference was noted in the quality of refrigerated sea-water-cooled and ice-cooled fish of the same catch (Lots 11 and 12 vs. Lot 13, Table 2 and Table 3), nor was there a significant difference in quality noted in fish exposed to air in the 30° to 31° F. (—1.1° to —0.5° C.) storage room and in those buried in ice in the same refrigerated room (Lots 1, 2, 3, 4, Table 1; and Lots 11, 12, Tables 1 and 2).

As indicated by most aspects, the fish sprinkled with salt at sea, then iced ashore (Lot 24, Tables 1 and 2) were markedly inferior to the fish iced at sea without the addition of salt. The salted fish, canned on the same day as caught, were not acceptable. They were poor in color, reddening being prevalent; stomachs were unattractive; texture and flavor were poor.

Air-frozen Sardines. Frozen fish stored for 22 to 43 days prior to canning were inferior, when thawed, to the recently-caught, unfrozen catch and about equal to unfrozen fish held 3 days under refrigeration. The color of the flesh of the fish held 43 days in cold storage was satisfactory. For these fish the odor of the outside of the gills and of the viscera was slightly to strongly rancid but that of the fish flesh itself was satisfactory to only slightly rancid, being superior in the glazed fish. The texture of the fish which had been frozen was firm to slightly soft, but acceptable. The reduction in quality of the frozen fish progressed slowly with length of storage on some counts while on others there was little or no observed deterioration after the initial reduction observed in the frozen fish. The glazed and unglazed frozen fish developed progressively stronger odors in the gills, viscera, and on the fish flesh with storage time. There was little concrete evidence to show increase in broken bellies, deterioration in texture or in color over the same periods.

After canning, deterioration in quality, as reflected by worsening of flavor, color, and in some instances texture, was shown to progress with length of storage prior to canning. Sub-lots 22 and 26 days in cold storage proved to be acceptable as raw material for canning, while those held 43 days in cold storage were on the borderline of acceptability. Those stored for longer periods were not acceptable. The major deficiencies in the pack

TABLE 3

Estimated storage life of sardines chilled wholly in ice vs. sardines chilled partially in ice and partially in refrigerated sea water (Lot No. corresponds to Lot No. given in Table 1)

Catch No.	Lot No.	Method of cooling and storing uneviscerated fish	Storage life prior to canning based on organoleptic examination of the canned product for color, texture, and flavor
			(days)
I	1 and 2	Iced at sea and ashore and held in 30 to 31° F. (—1.1 to —0.5° C.) holding room.	3
IV	13	Iced at sea and ashore and held in 30 to 31° F. (—1.1 to —0.5° C.) holding room.	3
VI	18	Iced at sea and ashore and held in 30 to 31° F. (—1.1 to —0.5° C.) holding room.	3
II	3	Iced at sea and partially cooled. Completely cooled in refrigerated sea water on shore, then held in 30 to 31° F. (—1.1 to —0.5°C.) holding room.	2
IV	11 and 12	Iced at sea and partially cooled. Completely cooled in refrigerated sea water on shore, then held in 30 to 31° F. (—1.1 to —0.5°C.) holding room.	3

from the fish held 43 days in low temperature storage, were broken bellies, strong odor, fair to poor color, and poor flavor.

Major differences in odor were observed in the air-frozen unglazed and air-frozen glazed fish prior to canning, those of the unglazed fish being more rancid. For periods of storage substantially longer than about 30 days, the unglazed fish yielded a canned product inferior to that produced from the glazed fish.

Brine-frozen Sardines. Little difference was noted in quality of the air-frozen and brine-frozen fish prior to canning. Generally, fillets from the brine-frozen fish appeared somewhat firmer than those from the air-frozen. The scoring for rancid odors on the exteriors and on the fish flesh showed the brine-frozen sardines of Catch IV in particular to be inferior to air-frozen fish of the same catch.

Fish 22 and 26 days in cold storage proved to be unacceptable as raw material for canning on the basis of the development in the canned fish of (a) objectionable reddening in the flesh along the back and lateral bones (b) objectionable flavors. In contrast, fish 43 days in storage (Catch IV) were acceptable for canning but had deteriorated greatly with longer storage.

Chemical examination.

Unfrozen Sardines. Peroxide development in sardines, handled in various ways, was low and about the same for a period of storage up to 3 days. Thereafter the fish landed un-iced and the fish sprinkled with salt at sea showed a higher peroxide development than the fish iced at sea. It was not possible, however, on the basis of peroxide content, to decide upon a definite storage limit for any of the lots of unfrozen fish.

Air-frozen and Brine-frozen Sardines. Curves A, B, and C (Figure 1) show peroxide determinations for brine-frozen unglazed, air-frozen and glazed, and air-frozen unglazed fish of Catch III respectively. Results for Catch II are in close agreement while curves D, E, F (Figure 1) for Catch IV show a much slower development. The latter fish were better handled and iced at sea than were Catches II and III. Of all catches, values were consistently highest for the brine-frozen fish, next highest for the air-frozen unglazed fish, and lowest for the air-frozen glazed fish. The curves fail to indicate a definite storage limit for the frozen product. Nevertheless, the amount of peroxide appears to be a good index of the handling and storage conditions. Banks *(5)* used a value of 50 ml. 0.002 N-thiosulphate per g. of fat to establish the limit of storage for frozen herring at —4° F. (—20° C.); this level was reached after about 16 weeks of storage. Results from the storage of sardines at this temperature using the same level of peroxide development and an average of the curves given in Figure 1, show the limit of storage to be about 40 days. It should be noted that results given above of the organoleptic examination of the sardines canned from the same supply of fish also suggest a maximum storage time of approximately one month.

As would be expected, retorting was shown to result in a general breakdown of peroxides in all lots of fish. The breakdown was not as complete in the product processed from the older frozen fish as in that processed from frozen fish in storage for shorter periods or that processed from fresh fish and from fish in unfrozen storage. Peroxide values were highest for fish which had been brine-frozen, next highest for the air-frozen unglazed fish, and lowest for the air-frozen, glazed fish.

There was little variation in free fatty acids in the canned fish whether the fish were iced at sea or upon landing, and whether the chilled fish were stored uneviscerated or eviscerated. The canned product from fish which had been salted at sea, then iced ashore, showed a higher free fatty acid content than did that canned from unsalted fish when the raw material was 4 days or less in storage prior to canning.

Fatty acid content of the canned fish was independent of the

TABLE 4

Salt content of the canned fish (air-frozen fish and fresh fish controls used for canning)

Catch No.	Days in cold storage	Lot No. of unglazed fish used for canning (corresponds to lot no. given in Table 1)	% Salt	Lot No. of glazed fish used for canning (corresponds to lot no. given in Table 1)	% Salt
II	26	7	1.60	6	1.45
II	72	7	1.15	6	2.10
II	103	7	0.90	6	2.60
II	153	7	0.80	6	.....
II	0 (fresh controls)	....	1.58	....	1.58
IV	43	16	1.43	15	4.14
IV	74	16	1.03	15	.....
IV	0 (fresh controls)	....	1.40	....	1.40

storage time of the frozen raw material, irrespective of freezing in air or in brine and of the presence or absence of a glaze over the fish. Very low values for free fatty acids were obtained, e.g., the degree of acidity averaged about 2.5 ml. N-NaOH per 100 g. of oil over the full period of cold storage of 153 days (Catch II).

Table 4 shows that the canned product of unglazed air-frozen fish carried little if any more salt than did that of fresh fish. Glazed air-frozen fish after brining and processing had a higher salt content than did air-frozen unglazed fish similarly treated. No explanation is known for this occurrence. The unglazed brine-frozen fish when brined and canned was much more salty than the fish brined and canned from the fresh supply (Table 5). This increase, probably the result of too slow freezing in brine and too high a storage temperature, was sufficient to raise the salt content of the fish canned from brine-frozen fish above the percentage acceptable from the standpoint of taste, this being about 2%.

TABLE 5

Salt content of the canned fish (brine-frozen fish and fresh fish controls used for canning)

Catch No.	Days in cold storage	Lot No. of unglazed fish used for canning (corresponds to lot no. given in Table 1)	% Salt
II	26	5	4.25
II	72	5	3.80
II	103	5	3.53
II	153	5	2.52
II	0 (fresh controls)	....	1.58
IV	43	14	1.54
IV	74	14	3.01
IV	0 (fresh controls)	....	1.40

DISCUSSION

Various exterior aspects of both frozen and unfrozen sardines, such as the appearance of the eyes and the gills and the odor of the exterior, the viscera, and the gills, gave the impression that deterioration on storage was proceeding at a much faster rate than the apparent condition of the flesh of the fish indicated. Examination of fish prior to canning should take into account the condition of both the whole fish and the fish flesh. For this reason, estimated over-all storage life reported above has been judged without too much emphasis on the condition of the eyes and the viscera (Table 2). For frozen sardines, an examination of the fish prior to canning may be of less value than in the case of the unfrozen catch. For example, for Catch IV the air-frozen sardines 43 days in storage appeared to be inferior to recently-caught, unfrozen fish but not appreciably inferior to 3-day-old unfrozen fish. In contrast, examination of fish processed from the same frozen and unfrozen sardines showed the frozen fish to be considerably inferior to the 3-day-old unfrozen catch. Organoleptic examination of brine-frozen fish prior to canning was found to give a poor indication of the quality of the fish after canning. Specifically, for both air-frozen and brine-frozen fish, extensive belly breakage, strong odors, and fair to poor color, not picked up in the raw material, were noted when the processed fish were examined. As an index of quality of the fish after canning, there would appear to be reason to question the infallibility of an organoleptic examination of fish thawed after removal from low temperature storage. This is probably mainly because of fat oxidation.

The present work suggests that organoleptic examination of unfrozen fish, to be of greatest value, should stress:

(1) Condition of belly wall.
(2) Odor of the fish flesh (particularly for eviscerated fish in storage).
(3) Age of fish since catching.

For frozen fish, thawed for processing, the organoleptic examination should stress:

(1) Odor of the fish flesh.

(2) Texture of the fish flesh.
(3) Condition of the belly wall.
(4) Age of the fish since catching.

The above factors should be correlated with examination of the canned product to give a proper assessment of quality.

The necessity of icing sardines soon after catching rules against the practice of transporting the fish uniced from grounds to factory when journeys of several hours are involved. The possibility of extending keeping time of the unfrozen fish to 3 days and of making freezing a worthwhile proposition exists only when fish are iced either on the grounds or at a nearby shore location and when the fish are handled without crushing in their cases both before and after icing.

Cooling by means of finely crushed or flaked ice is effective. It is of no benefit to supplement such chilling means later by cooling in refrigerated seawater. On the other hand, it would be of value to measure the effect of the use of refrigerated seawater at time of catching in comparison to the effect of the use of ice.

Peroxide development was greatest in brine-frozen fish. This parallels experience with the storage of herring *(4)*. While rancidity may be the limiting factor in determining the conditions of storage of sardines, other factors play a significant part in determining the quality of the frozen fish. To illustrate, the fish canned from the glazed and unglazed air-frozen lots (Catch IV, Lots 15, 16) were judged to be on the borderline of acceptabilty due to inferior flavor, color, and texture yet brine-frozen fish of the same catch which showed a higher peroxide development than did the air-frozen fish (Figure 1) yielded an acceptable canned product.

Commercial air-freezing and storage of sardines should be conducted under better conditions than were available for these experiments. A storage temperature at least as low as —20° F. (—29° C.) is recommended. Dry freezing in blocks with subsequent glazing and use of antioxidants such as ascorbic acid or possibly BHA (Butylated hydroxyanisole) should be considered to reduce oxidation during storage. These practices might extend appreciably the storage life of one month deter-

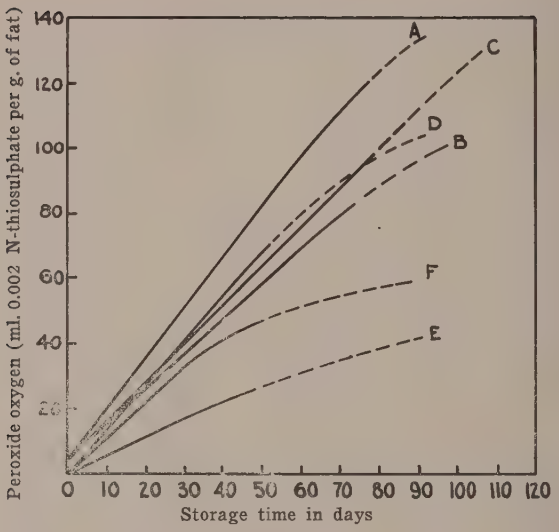

Figure 1. The oxidation of the fat in sardines stored at —4° F. (—20° C.).

B. Sardines of Lot 9, Catch III, frozen in rapidly moving air, then glazed and stored in still air.

E. Sardines of Lot 15, Catch IV, treated in the same manner as B.

C. Sardines of Lot 10, Catch III, frozen in rapidly moving air, and stored unglazed in still air.

F. Sardines of Lot 16, Catch IV, treated in the same manner as C.

A. Sardines of Lot 8, Catch III, frozen in brine of eutectic concentration and stored unglazed in still air.

D. Sardines of Lot 14, Catch IV, treated in the same manner as A.

mined by these experiments. Attention is drawn also to information from Norway on the use of alginate jellies for freezing *(13, 19)* as this technique might well be applicable to the Yugoslav-caught sardine. Norwegian techniques of freezing in metal boxes and thawing by means of water used on the outside of the boxes *(12)* should be considered as well since it is necessary to keep the percentage of waste resulting from broken fish to a minimum.

While brine-freezing of sardines should not be discouraged if the method appears to have an economic advantage, commercial freezing should be preceded by

still further experimental freezing to determine minimum standards for reddening of the flesh and salt uptake by the fish as the result of such freezing and subsequent dry storage.

It is recommended also that the salt content of the fish both before and after defrosting in water be established and that brining of the sardines prior to drying be controlled to give an acceptable salt content for the canned product.

CONCLUSIONS AND RECOMMENDATIONS

Sardines, to be of good canning quality, should be iced in boxes within two or three hours of catching in a manner which prevents crushing. Fish handled in this manner should be held no longer than three days in unfrozen storage prior to canning. Evisceration of sardines prior to storage is not necessary once these conditions are observed. After the sardines are cooled and placed in storage at 30 to 31° F. (—1.1 to —0.5° C.), the presence or absence of ice over the fish does not affect the quality of the fish for canning.

Only strictly fresh sardines, iced and handled as specified, should be frozen for later canning. Glazed and unglazed air-frozen sardines can be held at a temperature of —4° F. (—20° C.) in a condition acceptable for canning for a period of up to one month. A storage temperautre of about —20° F. (—29° C.) is recommended for use in commercial practice.

Organoleptic examination of the fish flesh both prior to and after canning is recommended to give a proper assessment of quality for canning.

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THE NON-ENZYMIC REDUCTION OF TRIMETHYLAMINE OXIDE TO TRIMETHYLAMINE, DIMETHYLAMINE, AND FORMALDEHYDE[1]

By E. B. Vaisey[2]

Abstract

Trimethylamine oxide at temperatures between 22°–24° C. is readily reduced by cysteine in the presence of iron or hemoglobin as a catalyst. Trimethylamine is the major product of this reduction, but appreciable amounts of dimethylamine and formaldehyde are also formed. The maximum reduction of trimethylamine oxide is between pH 7 and 8. Glutathione could not replace cysteine as a reducing agent, neither could copper or manganese replace iron compounds as catalysts. Larger amounts of iron (Fe^{++}) could also reduce trimethylamine oxide with the formation of the above products. A mechanism for the reaction is proposed.

Introduction

Dimethylamine (DMA) and trimethylamine (TMA) in certain dead marine fishes arise mostly as a result of bacterial activity; for this reason the determination of these compounds has been used as a spoilage index (2, 3, 16, 17). Although it is well known that the precursor of TMA is trimethylamine oxide (TMAO) (3), the precursor of DMA has not been discovered.

TMAO is decomposed into TMA, DMA, and formaldehyde by heating above 100° C. (9). Hydrolysis of the sulphur dioxide salt of TMAO resulted in the formation of similar products (14). Reay and Shewan (15) reported that bacteria, able to produce DMA in fish muscle juice, failed to produce it in a synthetic medium also containing the oxide. We have observed that washed cell suspensions of *Serratia marcescens* produced only TMA during the reduction of TMAO in media buffered at pH 6.5, 7.0, and 7.5, containing glucose as a hydrogen donator.

However, since TMAO was the precursor of DMA in the above chemical experiments, it was decided to investigate the possibility of reducing TMAO by chemical means, under conditions similar to those of the biological experiments reported above. Ackermann *et al.* (1) reported the reduction of TMAO by cysteine. Moreover cysteine can only reduce molecular oxygen in the presence of certain metals (4). The reduction of TMAO by cysteine in the presence of iron has therefore been more carefully studied.

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F.R.B. No. 456

Materials

Inorganic chemicals.—Reagent grade or better.

Trimethylamine hydrochloride.—Reagent grade trimethylamine hydrochloride is generally contaminated with dimethylamine. The latter was removed by treating a solution of the amine hydrochloride with a solution of sodium nitrite at room temperature, and extracting the nitrosamines thus formed with ether. The aqueous solution was then made strongly alkaline and distilled into concentrated hydrochloric acid. The trimethylamine hydrochloride crystals obtained after evaporation of the acid mixture were recrystallized twice from ethanol. The product (100 mgm. sample) was found to be free of dimethylamine when tested by the method given below.

Trimethylamine oxide dihydrate.—Trimethylamine hydrochloride, prepared as above, was made strongly alkaline and distilled into cold 3% hydrogen peroxide (9). When the peroxide mixture had stood for 24 hr. at room temperature, a few small pieces of clean sheet platinum were added to catalyze the decomposition of the excess peroxide. After standing a further 24 hr., the platinum was removed and the mixture was concentrated by distillation at 65° C. under reduced pressure. The trimethylamine oxide crystals so obtained were recrystallized once from ethanol and twice from ethanol–acetone. The product melted at 96° C. as reported for trimethylamine oxide dihydrate (8), and a 100 mgm. sample was found to be free of hydrogen peroxide when tested by the very sensitive method of Denigès (6).

Hemoglobin.—A 1% solution of hemoglobin (Difco) was dialyzed overnight against distilled water.

L-*Cysteine hydrochloride.*—Nutritional Biochemical Corporation.

Methods

The reactions were performed in 15-mm. test tubes at room temperature (22°–24° C.). The reaction solutions generally contained TMAO, cysteine, catalyst, and buffer as indicated under Figs. 1, 2, or 3. Phosphate buffer seriously interfered with the reactions. Substitution of veronal buffers was satisfactory if the solution of cysteine was previously adjusted to the pH of the buffer. Anaerobic techniques were not adopted in these experiments since under nitrogen the yield only increased by about 6%.

The reaction was stopped when desired by precipitating cysteine with a slight measured excess of cadmium acetate or by precipitating hemoglobin when present with trichloroacetic acid added to establish a concentration of 5%. After centrifugation, the volatile amines were removed from an aliquot of the supernatant fluid by the Conway technique of Beatty and Gibbons (3) after diffusion for two hours at 37° C. The resultant acid mixture was made up to volume and analyzed for TMA by the method of Dyer (10) and for DMA by Dyer's modification (11) of the method of Dowden (7). The sensitivity of these methods was such that it was possible to measure a 0.5% reduction of

TMAO to TMA and a 0.25% reduction of TMAO to DMA, under the conditions of these experiments. The specificity of assay for TMA and DMA was established under the conditions of the experiments.

Experimental

Fig. 1 shows the rate at which TMA and DMA are formed during the reduction of TMAO with iron and hemoglobin as catalysts. It is not justifiable to compare the reaction rates of the two catalysts, since the iron content of hemoglobin is 0.33%, so that the ratio of iron in the two experiments was about 6 : 100. The iron-catalyzed reaction was believed to be very near the equilibrium point when the experiment was terminated, for about this time, the violet color of the ferric–bicysteine complex disappeared.

Experiments similar to those reported in Fig. 1 but of 90 min. duration, showed that neither copper nor manganese catalyzed the reduction of TMAO by cysteine. Nor could glutathione replace cysteine as a reducing agent in the presence of any of the above inorganic compounds. These metals are known to catalyze the autoxidation of either cysteine or glutathione (4). Their failure to catalyze the reduction of TMAO was perhaps due to an

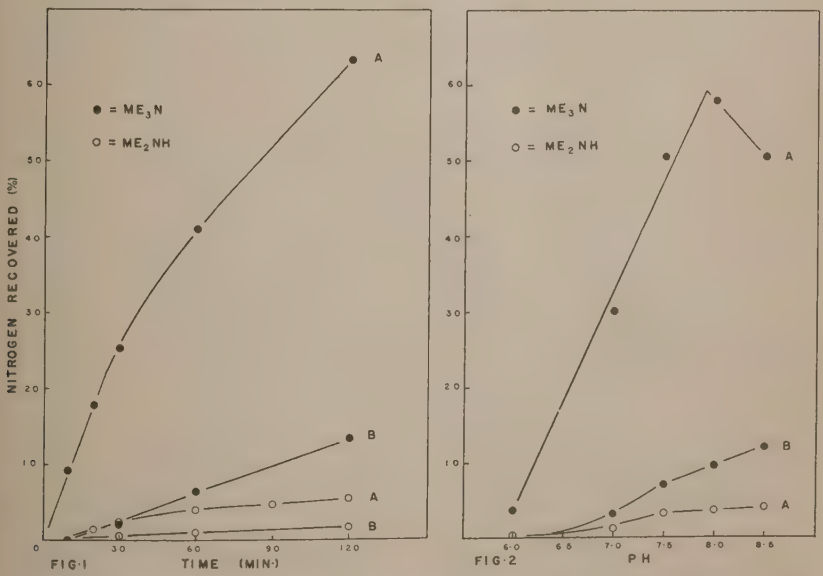

FIG. 1. TMAO reduction rate in the presence of cysteine with iron (A) and hemoglobin (B) as catalysts. Reaction mixture contained 1 ml. of 0.05 *M* TMAO, 1 ml. of 0.1 *M* cysteine, 1 mgm. of $FeCl_2 \cdot 4H_2O$ or 20 mgm. of hemoglobin, and sufficient 0.05 *M* veronal buffer at pH 7.5 to give a final volume of 6 ml.

FIG. 2. Effect of pH on TMAO reduction rate in the presence of cysteine with iron (A) and hemoglobin (B) as catalysts. The reaction mixture was similar to that described in FIG. 1 except that 0.05 *M* phthalate buffer was used to obtain a pH of 6.0. Incubation time about 75 min.

unfavorable oxidation–reduction potential of the appropriate substrate–metal complexes. The E_0' of the TMAO–TMA system is not known exactly, but Castell's work (5) would indicate that it is between +0.12 and +0.14 v. at pH 7.2.

Fig. 2 shows that the rate of reduction of TMAO with both iron and hemoglobin as catalysts is greater above pH 7. In the case of the iron-catalyzed reactions DMA formation was still increasing slightly at the termination of the experiment at pH 8.5, whereas TMA formation was maximum at about pH 8.0.

The results in Fig. 3 show that cysteine is unable to reduce TMAO without the mediation of a sufficient amount of catalyst. This was substantiated by the controls in the preceding experiments, but is contrary to the findings of Ackermann *et al.* (1). It seems probable that the cysteine used by these workers was contaminated with iron.

It may also be seen (Fig. 3) that the formation of both TMA and DMA increases with increasing iron concentration. It should be noted, however, that iron alone (curve B) is able to reduce TMAO to TMA and DMA when present in sufficient quantity. Ackermann *et al.* (1) also found that iron reduced TMAO to TMA, but they were apparently unaware that DMA was formed during the reaction.

Qualitative tests for formaldehyde, using chromotropic acid as described by Feigl (12), showed that it also was formed during the decomposition of TMAO.

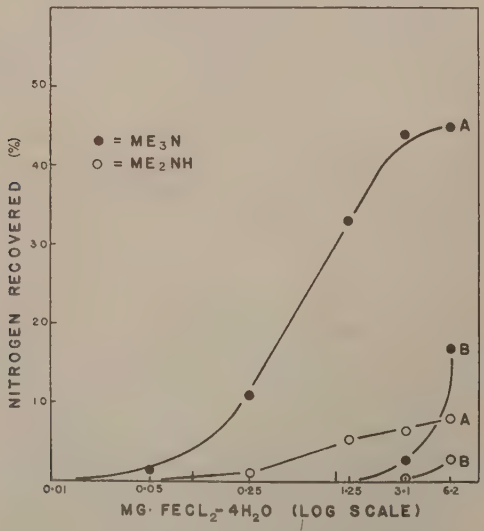

FIG. 3. Effect of various amounts of iron on TMAO reduction rate in the presence (A) and absence (B) of cysteine. The reaction mixture was similar to that described in FIG. 1. Incubation time about 45 min.

Discussion

The mechanism for the catalyzed reduction of TMAO by cysteine perhaps can be pictured as proceeding according to the equations below, although in reality it probably proceeds with the formation of catalyst–substrate intermediates. Equations 1 and 2 respectively represent the reduction and subsequent oxidation of iron, including hemoglobin iron, which allows them to function catalytically.

$$2RSH + 2Fe^{+++} \longrightarrow RS{-}SR + 2H^{+} + 2Fe^{++} \qquad [1]$$

$$(CH_3)_3N \longrightarrow O + 2H^{+} + 2Fe^{++} \longrightarrow (CH_3)_3N + 2Fe^{+++} + HOH \qquad [2]$$

$$(CH_3)_2N(H_2C{-}H) \longrightarrow O + H^{+} \longrightarrow \left[(CH_3)_2N{=}CH_2\right]^{+} + HOH \qquad [3]$$

I

$$\left[(CH_3)_2N^{\ominus}{-}CH_2\right]^{+} \xrightarrow{OH^{-}} (CH_3)_2N{-}CH_2{-}O{-}H \longrightarrow H_2C{=}O + (CH_3)_2NH \qquad [4]$$

I II

A mechanism to account for the formation of DMA and formaldehyde is shown in equations 3 and 4 and is based on the evidence that they occur as a consequence of the reduction of TMAO. The possibility that they were formed by an intermolecular reaction between TMA and TMAO was eliminated upon failure to detect DMA in solutions buffered at pH 7 containing TMA, TMAO, and catalytic amounts of iron. A second possibility that TMAO rearranged to form O,N,N-trimethylhydroxylamine was also eliminated when it was found that Jones and Major (13) had prepared this hydroxylamine. They reported the compound as being fairly stable under ordinary conditions and that it decomposed on heating with strong hydrochloric acid to monomethylamine, methyl chloride, and formaldehyde.

Comparing the results and experimental conditions of the catalytic reductions of TMAO with the enzymic reductions mentioned in the introduction, it seems that the failure to detect DMA (15), can best be explained on the basis of enzyme specificity. If this is so, then TMAO is not likely to be the precursor of DMA in dead fish.

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SOME FACTORS AFFECTING CELLULOSE DIGESTION BY RUMEN MICROORGANISMS *IN VITRO*

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A previous report from this laboratory revealed that cellulose digestion by rumen microorganisms *in vitro* was markedly stimulated by such fishery by-products as whale solubles, herring solubles and herring stickwater as well as by a mixture of 18 amino acids (MacLeod and Brumwell, '54). Although much of the effect of the fishery by-products could be ascribed to their amino acid content, some evidence was obtained that other unknown factors might also be present and capable of stimulating cellulose digestion. The present study was undertaken to investigate this possibility further.

In the previous study a marked stimulation of cellulose digestion was obtained with the various supplements tested only when a more dilute inoculum of rumen liquid than it had previously been the custom to use (cf. Burroughs et al., '51) was employed. It was evident that additional information regarding the nutritional requirements of rumen microorganisms could be obtained only if an active inoculum washed as free as posible of rumen liquid was used.

Various compounds or groups of compounds have been reported to stimulate cellulose digestion by rumen microorganisms *in vitro*. These include glucose (Hoflund et al., '48) various water-soluble vitamins, purines and pyrimidines

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(Hall et al., '53; Bentley et al., '54), an amino acid mixture (MacLeod and Brumwell, '54), urea (Belasco, '54), some steroid compounds (Brooks et al., '54) and certain short-chain fatty acids (Bentley et al., '55; Bryant and Doetsch, '55).

Using a well-washed inoculum of rumen microorganisms, a chemically defined medium has been developed incorporating at their optimum levels those factors found to be effective in this study in stimulating cellulose digestion. The medium developed was then used to determine whether various natural materials have a capacity to produce a further stimulation of cellulose digestion. In the course of this study it was established that three amino acids, namely leucine, isoleucine and valine were primarily responsible for the strong stimulation of cellulose digestion previously shown to be produced by a mixture of 18 amino acids (MacLeod and Brumwell, '54).

EXPERIMENTAL METHODS

In vitro rumen fermentations were carried out in a series of 18 × 150 mm test tubes essentially as described previously (MacLeod and Brumwell, '54). Cellulose digestion was measured by determining the difference in the weight of a roll of vegetable parchment (dialyzer paper) before and after fermentation.

Preparation of the inoculum. Inocula washed with varying degrees of thoroughness have been employed in certain of the more recent studies of cellulose digestion by rumen microorganisms *in vitro* (Bentley et al., '55; Cheng et al., '55).

The following procedure, developed in this laboratory, was found to give rise to a cellulolytically active, washed inoculum of rumen microorganisms. Rumen liquid obtained at an abattoir from the paunches of freshly killed cattle was strained through cheese-cloth to remove gross particles. The strained liquid was centrifuged at low speed (125 × G) in a Servall SS-1 centrifuge for 5 minutes to remove as much non-bacterial matter as possible. The supernatant liquid was then cen-

trifuged at high speed (25,000 × G) for 25 minutes to sediment bacterial cells. The cells were resuspended in a solution containing glucose, cysteine and the same salts as were present in the basal medium. The concentrations of the latter in the wash solution were the same as those in the basal medium while glucose was present at a concentration which would provide the optimum level of glucose to the fermentation medium when the inoculum was added to the tubes. The resuspended cells were centrifuged, the supernatant removed and the cells again suspended in the wash solution. This operation was repeated twice. The cells were finally diluted with a volume of wash solution usually equal to one-fifth of the volume of the rumen liquid from which the cells were originally obtained and 2.5 ml of this suspension was added to each assay tube.

To ensure that the inocula used from assay to assay had approximately the same initial activity, a means of comparing the activity of the various inocula was developed. The time required for a given volume of the washed suspension of rumen microorganisms to reduce a solution of triphenyl tetrazolium chloride under standard conditions was determined. In this test 2.5 ml of the washed suspension was added to 2.5 ml of a solution containing 0.25 ml of 0.1% triphenyl tetrazolium chloride, 0.3 ml of 10% glucose and 1.0 ml of M/15 phosphate buffer. The time required to reduce the dye at 40° C. was then determined. Reduction times obtained with the inocula were correlated with the rates of the corresponding fermentations. Inocula reducing the dye in times ranging from 4 to 6 minutes were found to be the most satisfactory. Suitable adjustments in the volume of the suspensions could usually be made to obtain inocula having reducing times falling within this range.

Basal medium. The composition of the chemically defined medium found in this study to be capable of promoting the best cellulose digestion by rumen microorganisms *in vitro* is presented in table 1. Cellulose was added to the medium as a roll of vegetable parchment. Glucose was incorporated

into the medium with the inoculum. The mixture of salts used was the same as that employed previously (MacLeod and Brumwell, '54). The remaining components of the medium were added at levels established by experiment to be optimum under the conditions employed in this study.

TABLE 1

Composition of fermentation medium

COMPONENT	AMOUNT/20 ml
Cellulose	500 mg
Glucose	20 mg
Urea	18.45 mg
Cysteine	15 mg
Amino acid mixture [1]	4.0 ml
Vitamin mixture [2]	1.0 ml
Salts A [3]	1.71 ml
Salts B [4]	0.17 ml
$CaCl_2$	0.646 mg

[1] Amino acid mixture: DL-alanine, 2 gm; L-aspartic acid, 400 mg; L-glutamic acid, 1 gm; DL-threonine, 400 mg; DL-serine, 400 mg; glycine, 200 mg; L-lysine, 400 mg; L-methionine, 200 mg; L-cystine, 200 mg; L-arginine, 400 mg; L-proline, 200 mg; L-histidine, 200 mg; DL-phenylalanine, 400 mg; L-tyrosine, 200 mg; L-tryptophan, 200 mg; L-valine, 200 mg; L-leucine, 200 mg; L-isoleucine, 400 mg, in total volume of 500 ml.

[2] Vitamin mixture: riboflavin, 10 mg; pyridoxal, 2 mg; calcium pantothenate, 10 mg; thiamine, 10 mg; niacin, 10 mg; *p*-aminobenzoic acid, 2 mg; biotin, 100 μg; folic acid, 100 μg; vitamin B_{12}, 15 μg, in a total volume of 100 ml.

[3] Salts A: Na_2HPO_4, 86 gm; $NaHCO_3$, 26.25 gm; KCl, 3.75 gm; NaCl, 3.75 gm; $MgSO_4$, 1.30 gm; in a total volume of 1000 ml.

[4] Salts B: $FeSO_4(NH_4)_2SO_4 \cdot 6H_2O$,3.89 gm; $MnSO_4 \cdot 4H_2O$, 0.80 gm; $ZnSO_4 \cdot 7H_2O$, 1.43 gm; $CuSO_4 \cdot 5H_2O$, 0.625 gm; $CoCl_2 \cdot 6H_2O$, 0.337 gm, in 1000 ml of solution.

Fermentation technique. The technique employed in this investigation was only a slight modification of that described previously (MacLeod and Brumwell, '54). In the present investigation smaller test tubes (18 $\times$ 150 mm) were used. Each tube in each assay was prepared in duplicate. Before inoculation CO_2 gas was bubbled through the contents of each tube to produce anaerobic conditions and at the same time to lower the pH of the medium to the starting value of 6.9. To maintain anaerobic conditions and still provide a

means of making allowances for the production of fermentation gases, the tubes were capped with small rubber balloons.

It was found in preliminary studies that there was no particular advantage to adjusting the pH of the tubes during the course of the fermentation so long as the fermentation did not proceed too far. In this study the fermentation was terminated when visual inspection indicated that approximately 30 to 50% of the cellulose had digested in those tubes which were fermenting most rapidly.

EXPERIMENTAL

Response to amino acids. The previous study had revealed that cellulose digestion by rumen microorganisms was strongly stimulated by the addition of a mixture of 18 amino acids to the fermentation medium (MacLeod and Brumwell, '54). A similar response to amino acids was obtained using a washed inoculum of rumen microorganisms and the level of the mixture producing maximum stimulation in the medium was approximately the same as found previously to be optimum. To determine which of the amino acids in the mixture were responsible for the effect obtained, the 18 amino acids were first subdivided into three groups of 6 each. These groups were tested alone and in combination for their ability to promote cellulose digestion. It can be seen, table 2, that only one of the three groups, group C, was active and in this experiment it proved to be more active than the complete mixture. When the 6 amino acids in group C were divided into the two sub-groups C_1 and C_2, sub-group C_2 was found to have the same activity as that of C. Sub-group C_2 contained leucine, isoleucine and valine. Omission of each of the amino acids in turn from group C_2 indicated that each was making a contribution to the response produced by the mixture in this experiment.

Because the types of organisms composing the rumen population can be present in the rumen in differing proportions (Gall et al., '53) especially if the feeding regimen of the animals is not well controlled, one might expect some varia-

tion in the response of the population to growth factors from one time to another. For this reason, experiments of the type illustrated were repeated using inocula obtained from rumen liquid collected on numerous different occasions. On each occasion the sub-group containing leucine, isoleucine and valine was found to be responsible for most or all of the activity of the complete mixture. When the three amino acids

TABLE 2

The effect of groups of amino acids on cellulose digestion by rumen microorganisms in vitro

ADDITIONS TO MEDIUM [1]	% CELLULOSE DIGESTED [2]
None	7
Complete mixture	23
Group A	8
Group B	3
Group C	35
Group C_1	6
Group C_2	32
C_2 minus valine	18
C_2 minus leucine	8
C_2 minus isoleucine	12

[1] The medium of table 1 was used with the amino acid mixture omitted and the total nitrogen content of each tube maintained at 17.5 mg by the addition of an appropriate level of urea.

The various groups shown contained the following amino acids: A — alanine, aspartic acid, glutamic acid, threonine, serine, glycine; B — lysine, methionine, cystine, arginine, proline, histidine; C — phenylalanine, tyrosine, tryptophan, valine, leucine, isoleucine; C_1 — phenylalanine, tyrosine, tryptophan; C_2 — valine, leucine, isoleucine.

[2] Incubation time = 72 hours.

were tested alone and in combination on the different occasions, however, somewhat more variable results were obtained. Usually the three amino acids together were better than each tested singly or in pairs. In one case, however, the three amino acids were all equally active when tested individually while in another certain pairs were as good as all three. At no time was it found possible to obtain appreciable cellulose digestion without any of the three amino acids being present.

The results of the experiment recorded in table 2 indicate that in this case the complete amino acid mixture was less effective than the combination of leucine, isoleucine and valine in promoting cellulose digestion. In general, however, the complete mixture had at least the same and sometimes slightly more activity than the more limited number of amino acids. For this reason the complete mixture of amino acids rather than the combination of leucine, isoleucine and valine alone was included routinely in the preparation of the basal medium.

TABLE 3

A comparison of the ability of certain amino acids and fatty acids tested alone and in combination to promote cellulose digestion by rumen microorganisms in vitro

ADDITIONS TO MEDIUM [1]	% CELLULOSE DIGESTED [2]
None	29
Valine + leucine + isoleucine (12 μM of each)	51
Valine + leucine + isoleucine (24 μM of each)	47
Valeric + isovaleric acids (12 μM of each)	38
Valine + leucine + isoleucine + valeric acid + isovaleric acid (12 μM of each)	44

[1] See table 2.

[2] Incubation time = 91 hours.

Bentley et al. ('55) found that cellulose digestion by rumen microorganisms could be stimulated by certain short-chain fatty acids present in rumen liquid as well as by proline and valine. Bryant and Doetsch ('55) observed that *Bacteroides succinogenes*, a cellulolytic bacterium isolated from the bovine rumen, required a combination of a 5- to 8-carbon straight-chain fatty acid and a branched-chain fatty acid which could be either isobutyric, isovaleric or dl-α-methyl-n-butyric acid for growth. It was of interest to know whether the effect of these volatile fatty acids on cellulose digestion by rumen microorganisms was related to or independent of the response of the organisms to leucine, isoleucine and valine.

The results in table 3 show the response to a combination of valine, leucine and isoleucine when these were tested at the level at which they were present in the complete mixture used in the basal medium. Doubling the concentration of the amino acids had a slightly inhibitory effect. Valeric and isovaleric acids tested in combination at the same level as the three amino acids promoted cellulose digestion but not to quite the same extent as the amino acids. The addition of the fatty acids to a medium containing the three amino acids caused no further stimulation of cellulose digestion but actually a decrease similar to that obtained by adding an excess of the three amino acids.

There was thus no evidence of synergism when the amino acids and the short-chain fatty acids were tested together, but rather it would appear from these results that the two types of compounds were being used interchangeably in promoting cellulose digestion by the rumen microorganisms.

Response to vitamins. Hall et al. ('53) found that biotin and vitamin B_{12} were stimulatory to cellulose digestion *in vitro,* while Bentley et al. ('54) reported a response to biotin, vitamin B_{12} and *p*-aminobenzoic acid.

A mixture of 9 vitamins when added to the fermentation medium used in this study consistently stimulated cellulose digestion by the rumen microorganisms. Some difficulty, however, was encountered in establishing which vitamins singly or in combination contributed to the stimulation produced by the mixture. The results of one experiment, shown in table 4, reveal that on this occasion the omission of either pyridoxal, thiamine or niacin lowered the response of the micro-organisms to the vitamin mixture. In other experiments folic acid and *p*-aminobenzoic acid also appeared to play a role. Throughout these experiments, pyridoxal (replaceable by pyridoxamine or pyridoxine) was consistently effective in stimulating cellulose digestion. To ensure maximum stimulation from the water-soluble vitamins, the complete mixture was included in the basal medium at a level slightly in excess of that producing an optimum response.

Response to glucose. Hoflund et al. ('48) found that 0.1 to 0.2% of glucose in the medium stimulated cellulose digestion by rumen microorganisms *in vitro* while higher levels depressed it.

The effect of adding increasing concentrations of glucose to the fermentation medium used here is shown in table 5. In this experiment glucose was omitted from the wash solution used to prepare the inoculum.

TABLE 4

Effect of vitamins on cellulose digestion by rumen micro-organisms

ADDITIONS TO MEDIUM [1]	% CELLULOSE DIGESTED [2]
None	20
Complete vitamin mixture	36
minus riboflavin	33
minus pyridoxal	27
minus calcium pantothenate	35
minus thiamine	27
minus niacin	29
minus *p*-aminobenzoic	34
minus biotin	36
minus vitamin B_{12}	34
minus folic acid	35

[1] The medium of table 1 was used with the vitamin mixture omitted.
[2] Incubation time = 64 hours.

TABLE 5

Effect of increasing levels of glucose on cellulose digestion by rumen microorganisms in vitro

GLUCOSE ADDED [1]	% CELLULOSE DIGESTED [2]
mg/20 ml	
0	19
10	25
20	24
30	29
40	24
80	22
160	19

[1] The medium of table 1 was used with glucose omitted.
[2] Incubation time = 72 hours.

The results show that stimulation of cellulose digestion was obtained in the same range of glucose concentrations as that observed by Hoflund et al. The optimum response was obtained over a range of 10 to 40 mg per tube (0.05 to 0.2%) while decreased effects were observed at higher concentrations. Although the magnitude of the stimulation was not great, it was found that the routine inclusion of glucose at a 0.1% level in the medium greatly improved the reproducibility of all assay results.

TABLE 6

The relation of the cellulolytic factor added to the response of rumen microorganisms to urea

UREA ADDED [1]	CELLULOLYTIC FACTOR ADDED		
	Isovaleric + valeric acids	Amino acids Restricted [2]	Amino acids Complete [3]
mg/20 ml	*% cellulose digested* [4]		
0	11	16	27
18	27	26	36
27	30	35	38
36	32	39	42
45	34	38	25
54	28	23	0

[1] The basal medium used was that of table 1 with urea and the amino acid mixture omitted.

[2] Leucine + isoleucine + valine added at the level present in the complete mixture.

[3] Complete mixture of 18 amino acids (see table 1).

[4] Incubation time = 89 hours.

Response to urea. The presence of urea along with various food proteins in *in vitro* rumen fermentation studies has been found to improve cellulose digestion over that observed with the food proteins alone (Belasco, '54). In the present study, the level of urea needed for maximum stimulation of cellulose digestion varied depending on the "cellulolytic factor" employed. More was required if the combination of valeric and isovaleric acids was added than if amino acids were used, table 6. Even in the presence of the mixture of 18 amino acids the addition of urea was quite strongly stimulatory. Further increases in urea concentration beyond the level re-

quired for maximum activity brought about a decrease in the amount of cellulose utilized, in a manner similar to that observed by Belasco ('54). In the presence of the complete amino acid mixture, not only was less urea required for maximum cellulose digestion but also less was needed to produce inhibition. Thus there is a comparatively narrow range of nitrogen concentration producing optimum cellulose digestion, a factor to be considered when testing the growth-promoting activity of natural materials.

TABLE 7

Effect of various supplements on cellulose digestion by rumen microorganisms in the complete synthetic medium

SUPPLEMENT TO SYNTHETIC MEDIUM [1]	EXP. 1	EXP. 2	EXP. 3
		% cellulose digested	
None	33	41	46
Whale solubles	42	45	52
Herring solubles	35	41	54
Yeast extract	37	40	44
Enzymatic casein	36	41	36
Beef liver extract	41	48	.
Malt extract	28	38	. .
Herring stickwater	. .	. .	51

[1] The complete medium of table 1 was used as the basal medium. Each supplement was tested at a series of levels providing from 1.7 to 13.1 mg of nitrogen per tube.

Effect of miscellaneous supplements. Purines and pyrimidines as well as various steroid compounds have been reported to stimulate digestion by rumen microorganisms *in vitro* (Bentley et al., '54; Brooks et al., '54). Adenine, guanine, uracil and xanthine added alone and in combination to this basal medium at a level of 400 µg per tube had no stimulatory effect on the fermentation. The addition of cholesterol at a level of 400 µg per 20 ml of medium both alone and in combination with Tween 40 likewise did not affect cellulose digestion under the conditions used here.

Addition of natural materials to the fermentation medium. When all of the compounds found in this study to be active in

promoting cellulose digestion were combined at levels producing maximum activity, the medium shown in table 1 was obtained. To determine whether additional factors were active in stimulating cellulose digestion, supplements of various natural materials were added to the synthetic medium. The results obtained in three different experiments are summarized in table 7. Since the margin between the optimum and the inhibitory level of nitrogen in the medium was small and somewhat variable, each supplement was tested at a number of different levels in each experiment. The level of supplement at which a maximum response was obtained varied from one experiment to the next. The results reported in table 7 represent the maximum response obtained for each supplement in each experiment. It can be seen that certain of the supplements, particularly whale solubles and beef liver extract produced an appreciable stimulation of cellulose digestion over that obtained in the synthetic medium alone. The amounts of supplement required to produce a response, however, were quite large, ranging from 30 to 60 mg per tube.

DISCUSSION

In this study leucine, isoleucine and valine have been found to be interchangeable with short-chain fatty acids in promoting cellulose digestion by rumen microorganisms *in vitro*. Bentley et al. ('55) have found valine to be active in stimulating cellulose digestion in the absence of fatty acids. In studying the growth requirements of *Bacteroides succinogenes*, a cellulose digesting microorganism isolated from the bovine rumen, Bryant and Doetsch ('55) obtained a response of the organism to short-chain fatty acids in a medium containing an enzymatic digest of casein. The same brand of enzymatic casein at the level used by the latter authors has been found in this study to produce maximum cellulose digestion by rumen microorganisms and all attempts to increase the extent of digestion by adding either leucine, isoleucine and valine or short chain fatty acids have been unsuccessful. The difference in response obtained can probably be ascribed

to the fact that in the cases where amino acids and fatty acids have been found to be interchangeable a mixed culture of rumen microorganisms was used. Hungate ('50) has described 7 and Huhtanen and Gall ('53) 9 different bacteria or strains of bacteria isolated from the bovine rumen capable of digesting cellulose or fibre. It is of course possible that fatty acids are able to stimulate one and the amino acids another of these strains or group of strains. Knowledge of the growth requirements of other cellulolytic bacteria which have been isolated from the rumen in pure culture should prove of interest in connection with this possibility. The similarity in structure of the active amino acids and fatty acids, however, appears to be more than coincidental and it is likely that, in the mixed culture, organisms associated with the cellulose digesters can convert the appropriate amino acids to the specific fatty acids required by at least one strain of cellulose digesting microorganism. Evidence for the production of volatile fatty acids from amino acids by microorganisms from the rumen of sheep has been demonstrated by El-Shazly ('52). Of particular interest in connection with the work reported here is the fact that the latter author has postulated that the branched-chain C_4 and C_5 volatile fatty acids in the rumen are formed from valine, leucine and isoleucine as a result of Stickland type reactions.

Whether the response to supplements of natural materials, which was obtained in the fermentation, is due to one or more specific factors present in the supplements or to a more generalized response to the addition of large quantities of preformed growth factors to the medium has not been established. The relatively large amounts of the supplements required to obtain the responses observed suggests that the latter explanation could account for the effect. To make it profitable to pursue this phase of the problem further inocula obtained under more reproducible conditions than are presently available to this laboratory would be required.

SUMMARY

Using a washed inoculum of rumen microorganisms a chemically defined medium has been developed incorporating at their optimum levels those factors found to be effective in this study in stimulating cellulose digestion. In this medium responses to amino acids, short-chain fatty acids, various vitamins, glucose and urea have been demonstrated.

A combination of valine, leucine and isoleucine was found to be primarily responsible for the strong stimulation of cellulose digestion previously shown to be produced by a mixture of 18 amino acids. The combination of leucine, isoleucine and valine could be used interchangeably with and was somewhat more effective than the volatile fatty acids tested in promoting cellulose breakdown.

Of the various vitamins tested, vitamin B_6 was the most consistent in its ability to stimulate cellulose digestion by rumen microorganisms in the medium used.

The level of urea required for maximum stimulation of cellulose digestion varied depending on the cellulolytic factor employed. More was required if the combination of valeric and isovaleric acids was added than if amino acids were used. Optimum cellulose digestion occurred over a comparatively narrow range of nitrogen concentration in the medium. Above this range inhibition occurred.

When various natural materials, in particular whale solubles and beef liver extract, were added to the synthetic medium, some further stimulation of cellulose digestion over that obtained in the synthetic medium alone resulted. Relatively large amounts of the supplements were required to produce the additional response.

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The Kinetics of the Hydrogenation of Pure Fatty Esters. II. Mono-olefinic Systems: Cis-trans Isomerism

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THE FORMATION of *trans* isomers in the course of hydrogenation is considered a phenomenon of considerable importance to the commercial hardening of oils. It would seem desirable therefore, from a practical as well as from a theoretical standpoint, to obtain a satisfactory picture of the mechanism underlying *cis-trans* isomerism.

The contribution of Feuge *et al.* (2) toward a solution to this problem is important for several reasons, in particular, in supplying reliable data through the use of an infrared spectrophotometric method established by Swern and co-workers (4). These data show many points of similarity between the behavior of triolein and that of methyl oleate over a wide range of conditions. One of the salient features of the reaction, as revealed by this study, is the gradual evolution of the system toward a *cis-trans* equilibrium. Another feature is the necessity of the presence of hydrogen for the formation of *trans* isomers, in contrast with *cis-trans* isomerization reactions, such as those promoted by selenium. A possible explanation is that the adsorbed complex formed from hydrogen, nickel, and the unsaturated compound is the origin of both the saturated compound and the isomeric unsaturated form. It is probable that a certain proportion of the complex units, instead of being released from the catalyst in the form of saturated molecules, break down and revert to the constituents. Unsaturated constituents so released could be either *cis* or *trans* if the structure

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of the complex were such as to allow free rotation between the carbon atoms originally linked by a double bond. It is one of the purposes of the present article to show that the above postulate is consistent with hydrogenation data. For this purpose, data which Swicklik *et al.* tabulated in a recent article (3) will be used.

These authors have carried out experiments similar to those of Feuge *et al.* with a view to checking a postulated mechanism of the reaction. They concluded that a true first order model for the reactions involved was incompatible with the data. Good agreement was obtained when all rate constants were multiplied by the same function, $1 + at$, indicating, in their opinion, that the effectiveness of the catalyst increased with time. In their experiment No. 2, for example, the effectiveness of the catalyst would have increased four times by the end of the reaction. This would seem difficult to reconcile with the fact that the over-all hydrogenation rate was very constant throughout. It is another purpose of the present article to explain this and other puzzling facts, using to this end conclusions relative to zero order hydrogenation kinetics enunciated in Part I of the present series (5).

It is probable that a systematic study of the reaction by the method initiated by Feuge *et al.* will ultimately provide considerable help to the technologist by removing much empiricism from commercial hydrogenation practice. This would result from a comparison of reaction rate constants under various conditions. A simple method for the computation of these rate constants is given below.

Proposed Mechanism

Figure 1 describes the various phases of the reaction involving a system initially composed of a *cis* mono-olefinic ester, a nickel catalyst, and hydrogen. The temperature is assumed high enough to promote formation of *trans* isomers. Double bond shifts also occur, but adsorptive and reactional behaviors are assumed to be identical for all forms which are geometrical homologues. Thus $\overline{A}$ represents all the *cis* and $\overline{B}$ all the *trans* homologues.

Figure 1 depicts the adsorptive equilibria between $\overline{A}$ and $\underline{A}$ and between $\overline{B}$ and $\underline{B}$; $\underline{A}$ and $\underline{B}$ are the respective adsorbed forms. It shows the reactions leading to the formation of complexes $\underline{AHH}$ and

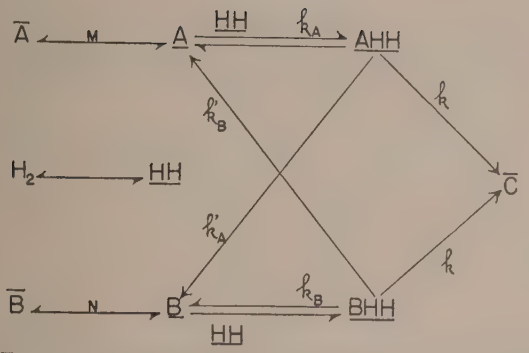

FIG. 1. Diagram describing a mechanism proposed for the hydrogenation of methyl oleate or triolein in the presence of a nickel catalyst.

BHH from adsorbed hydrogen HH and, respectively, A and B. A constant proportion k of complex AHH is shown to be released every minute, forming C, the fully saturated compound. Another fraction k'_A breaks down, releasing HH and B. Still another breaks down, reverting to its original constituents A and HH; the reaction is one of the opposed reactions in the equilibrium between A, HH, and AHH. Constant k_A is the equilibrium constant by Guldberg and Waage's principle for this reaction.

The fate of complex BHH parallels that of AHH. The complexes are assumed to form concurrently to the opening of a double bond. During the short half life of the complex, free rotation along the residual carbon-carbon linkage would occur to a variable extent. Particularly large deviations from the original position would confer the isomerized status. Such "isomerized" complexes would yield the adsorbed isomerized form upon break-down.

The distinction between AHH and BHH is thus mainly of a statistical nature, and one would not expect properties, such as the stability of the complex-to-metal bond, to be different in either case. Hence it is assumed that the rate of release k is the same for both types. No assumption is made regarding the rates of break-down.

Basic Rate Equations

Let A, B, and C be the concentrations, expressed as percentages of total molar composition, for $\bar{A}$, $\bar{B}$,

and $\overline{C}$, respectively. Because of the system of two consecutive equilibria between $\overline{A}$ and $\underline{AHH}$, losses of $\underline{AHH}$ because of either $\overline{C}$ or $\underline{B}$ formation must be compensated by losses of $\overline{A}$ from the medium. A steady state may be considered in such transfers since the quantities transferred per minute are so much larger than the quantities involved in the coverages of $\underline{A}$ and $\underline{AHH}$. Thus for all practical purposes the rate of loss of $\underline{A}$ is equal to the rate of loss of AHH due to both $\overline{C}$ and $\underline{B}$ formation. On the other hand, the rate of gain of concentration A through the series of transfers described by

$$\underline{BHH} \longrightarrow \underline{A} \longrightarrow \overline{A}$$

is equal to the rate at which $\underline{BHH}$ produces $\underline{A}$.

If $\underline{a}$ represents the total coverage for $\underline{AHH}$ and $\underline{b}$ the total coverage for $\underline{BHH}$, the over-all rate of change of concentration $\overline{A}$ is thus expressed by

$$dA/dt = -\underline{a}k - \underline{a}k'_A + \underline{b}k'_B \qquad (1)$$

A similar reasoning leads to

$$dB/dt = -\underline{b}k - \underline{b}k'_B + \underline{a}k'_A \qquad (2)$$

for the over-all rate of change of concentration B. The rate of change of concentration C is evidently

$$dC/dt = \underline{a}k + \underline{b}k \qquad (3)$$

Expressions for Complex Coverages

It has been shown in Part I of this series of articles that two different cases may arise, depending on the abundance of hydrogen supplied. If the medium is kept saturated with hydrogen, the hydrogen coverage is large and the reactions leading to the formation of complexes do not compete. If the hydrogen supply is limited by diffusion, the hydrogen coverage falls to a very low level and the reactions leading to the complexes will compete for their share of hydrogen. In both cases the hydrogen coverage is a constant, and the coverages of adsorbed unsaturated species are proportional to the concentrations of these species in the medium. Thus coverages for $\underline{A}$ and $\underline{B}$ would be expressed by

$$\mu_A = PMA \qquad (4)$$
$$\mu_B = PNB$$

where M and N are the respective adsorption equilibrium constants and P is a proportionality constant, depending on catalyst area and the extent of hydrogen coverage.

Let $\underline{h}$ be this coverage. The postulated mechanism has shown an equilibrium between $\underline{A}$, $\underline{HH}$, and $\underline{AHH}$. This is expressed by

$$\underline{a} = k_A \mu_A \underline{h} = k_A PMA\underline{h}$$

Similarly

$$\underline{b} = k_B \mu_B \underline{h} = k_B PNB\underline{h}$$

Let

$$k_A M = k_{03} \quad ; \quad k_B N = k_{02} \quad ; \quad P\underline{h} = S \tag{5}$$

The above expressions then become

$$\underline{a} = k_{03} AS \tag{6}$$
$$\underline{b} = k_{02} BS$$

These expressions are true only when there is no competition for adsorbed hydrogen (saturated medium).

In the second case, characterized by zero order kinetics, the over-all rate of hydrogenation is a constant. Let k_C be this constant.

Hence, from equation (3),

$$\underline{a} + \underline{b} = k_c / k \tag{7}$$

By analogy with homogeneous competitive reactions of the first order, $\underline{a}$ and $\underline{b}$ are proportional to their values when the reactions are not competing. Hence, from equations (6) and (7),

$$\underline{a} = k_c k_{03} A / (k_{03} A + k_{02} B) k$$
$$\underline{b} = k_c k_{02} B / (k_{03} A + k_{02} B) k$$

Introducing

$$k_c / (k_{03} A + k_{02} B) = e^{\alpha t} \tag{8}$$

these expressions become

$$\underline{a} = k_{03} A e^{\alpha t} k^{-1} \tag{9}$$
$$\underline{b} = k_{02} B e^{\alpha t} k^{-1}$$

Final Expressions of Rates and of System Composition

Considering the case when zero order conditions are established, the values for a and b given by equations (9) are substituted in equations 1, 2, and 3. Let

$$k'_A k_{03} k^{-1} = k_{01} \quad ; \quad k'_B k_{02} k^{-1} = k_{04} \tag{10}$$

These expressions then become:

$$dA/dt = -(k_{01} + k_{03})Ae^{\alpha t} + k_{04}Be^{\alpha t} \tag{11}$$

$$dB/dt = -(k_{02} + k_{04})Be^{\alpha t} + k_{01}Ae^{\alpha t} \tag{12}$$

$$dC/dt = k_{03}Ae^{\alpha t} + k_{02}Be^{\alpha t} = k_c \tag{13}$$

Let

$$e^{\alpha t}dt = d\theta$$

Then

$$\theta = (e^{\alpha t} - 1)\alpha^{-1} \tag{14}$$

The above system of differential equations then becomes identical in form to equations (12), (13), and (14) of Swicklik *et al.* The solution of these equations is thus

$$A = c_1 e^{m_{01}\theta} + c_2 e^{m_{02}\theta} \tag{15}$$

$$B = \frac{k_{01}c_1 e^{m_{01}\theta}}{m_{01} + k_{02} + k_{04}} + \frac{k_{01}c_2 e^{m_{02}\theta}}{m_{02} + k_{02} + k_{04}} \tag{16}$$

$$C = 100 - (A + B) \tag{17}$$

where θ has the value given by (14) and

$$m_{01} = \left(-b + \sqrt{b^2 - 4c}\right)0.5 \tag{18}$$

$$m_{02} = -b - m_{01} \tag{19}$$

with

$$b = k_{01} + k_{02} + k_{03} + k_{04} \tag{20}$$

$$c = (k_{01} + k_{03})(k_{02} + k_{04}) - k_{01}k_{04} \tag{21}$$

Expressions for the composition, when the medium is saturated with hydrogen, are obtained by substituting θ by Skt in the above.

Determination of the Rate Constants

In the following demonstration the data tabulated by Swicklik *et al.*, corresponding to their experiment No. 2, a typical case of over-all zero order kinetics are used. Figure numbers cited refer to theirs also.

a) When $t = 0$,

$$A = 100 \quad ; \quad B = 0 \quad ; \quad e^{at} = 1$$

Introducing these values in equation (13),

$$dC/dt = 100\, k_{03} = k_c$$

Hence the value of k_{03} is found from the slope of the line obtained on plotting C *vs.* time. From Figure 3,

$$k_c = 0.69$$

Thus

$$k_{03} = 0.69 \times 10^{-2}$$

b) Introducing in equation (11): $t = 0$, $A = 100$, $B = 0$, $e^{at} = 1$

$$dA/dt_{t=0} = -(k_{01} + k_{03})10^2$$

The value of $dA/dt_{t=0}$ is found from the plot $\log_{10}A$ *vs.* time in Figure 1; the required value is that of the slope of the line, near the ordinate axis, multiplied by $\log_e 10 = 2.302$. Subtracting from the result the value of $100k_{03}$ yields $100k_{01}$. One finds

$$k_{01} = 2.18 \times 10^{-2}$$

c) When B reaches its maximum (Figure 3), dB/dt is equal to zero. Equation (12) then yields, upon simplifying by $e^{at} \neq 0$, and rearranging:

$$k_{02} + k_{04} = k_{01}A/B$$

Introducing the values of B maximum and the corresponding value for A (respectively, 43 and 26) taken from Figure 3, and the value of k_{01},

$$k_{02} + k_{04} = 1.319 \times 10^{-2}$$

d) It will be shown that both m_{01} and m_{02} have negative values, m_{02} being much larger in absolute value than m_{01}. As a consequence the exponentials containing m_{02} become negligible when t is large. Equations (15) and (16) then reduce to

$$A = c_1 e^{m_{01}\theta}$$

$$B = k_{01} c_1 e^{m_{01}\theta} / (m_{01} + k_{02} + k_{04})$$

By dividing:

$$B/A = k_{01} / (m_{01} + k_{02} + k_{04}) \qquad (22)$$

The slope of plot B *vs.* A should thus assume a constant value toward the end of the reaction. This is found indeed. The value of the slope (for points corresponding to the 90th, 105th, and 120th minutes) is 2.5.

Hence

$$k_{01} / (m_{01} + k_{02} + k_{04}) = 2.5$$

Introducing the values found for k_{01} and for $k_{02} + k_{04}$,

$$m_{01} = -0.477 \times 10^{-2}$$

e) Introducing in expression (18) the values of $k_{01} + k_{03}$, $k_{02} + k_{04}$, k_{01}, and m_{01},

$$-0.477 \times 10^{-2} = \left(-4.189 + \sqrt{2.89 + 8.72\, k_{04}}\right) \times 0.5 \times 10^{-2}$$

Hence

$$k_{04} = 0.97 \times 10^{-2}$$

Consequently, from the value of $k_{02} + k_{04}$,

$$k_{02} = 0.349 \times 10^{-2}$$

The above method of calculation applies when zero order kinetics are still maintained when B reaches its maximum. This is the case for experiment No. 3 of Swicklik *et al.* The constants have also been calculated for this experiment. They are listed in Table I along with the values obtained for experiment No. 2 and in each case the values obtained by Swicklik *et al.*

Comparison Between Theoretical and Experimental Values

The use of equations (15), (16), and (17) requires numerical values of m_{02}, c_1, c_2, θ, and a. They are obtained as follows:

TABLE I

Comparison Between the Numerical Values (x 10^2) of Rate Constants Computed by Swicklik *et al.* and Those Obtained by the Author from the Same Data [a]

	Swicklik *et al.*		Vandenheuvel	
Hydrogenation No...	2	3	2	3
k_{01}	2.4	9.1	2.18	9.44
k_{02}	0.6	2.5	0.349	1.86
k_{03}	0.5	3.7	0.69	3.86
k_{04}	1.0	3.5	0.97	4.37
k_{02}/k_{03}	1.2	0.67	0.505	0.485

[a] Taken from Swicklik *et al.* (3).

a) Introducing in (19) the values of k_{01}, k_{02}, k_{03}, k_{04}, and m_{01},

$$m_{02} = -3.712 \times 10^{-2}$$

b) It is found from (14) that $\theta = 0$ when $t = 0$. At the same time $A = 0$. Equation (15) yields

$$c_1 + c_2 = 100$$

Deriving (15), one obtains:

$$dA/d\theta = m_{01}c_1 e^{m_{01}\theta} + m_{02}c_1 e^{m_{02}\theta}$$

Substituting $d\theta$ by $e^{at}\,dt$, it value by definition, then assuming $t = 0$, which implies $\theta = 0$, and $e^{at} = 1$,

$$\left(dA/dt\right)_{t=0} = m_{01}c_1 + m_{02}c_2$$

It has been shown that

$$\left(dA/dt\right)_{t=0} = -\left(k_{01} + k_{03}\right) \times 10^2$$

Hence

$$m_{01}c_1 + m_{02}c_2 = -10^2\left(k_{01} + k_{03}\right)$$

which can be solved with

$$c_1 + c_2 = 100$$

after introducing the values of m_{01}, m_{02}, k_{01}, and k_{03}, giving

$$c_1 = 25.8$$
$$c_2 = 74.2$$

c) From equation (8), replacing k_{02}, k_{03}, and k_C by their known values,

$$A + 0.505B = 100e^{-at}$$

Introducing corresponding experimental values of A, B, and t yields the following series of values for a

t	15	30	40	50	60	90	105	120
$a10^2$	1.67	1.73	1.73	1.63	1.65	1.62	1.69	1.86

Averaging the series,

$$a = 1.7 \times 10^{-2}$$

d) It is now possible to calculate values for θ from equation (14) and to replace all constants and parameters by numerical values in equations (15), (16), and (17). When the calculated values of A, B, and C are plotted against time, curves superimposable to the experimental ones but slightly displaced to the right are found. The shift corresponds to a time lag for the reaction of about 1 min.

Subtracting 1 min. from all values of time brings the calculated values in very good agreement with the experimental ones shown in Figure 2.

Discussion

Kineticists do not agree on the mechanism underlying the hydrogenation of the simplest olefin, *viz.*, ethylene. It would seem however that the associative theory is the more acceptable (1) and that hydrogenation is a two-step reaction involving a half-saturated stage. This concept was not used here because of the unnecessary complication it would introduce in the above demonstration. The changes it brings to the above scheme (Figure 1) amount to replacing $\underline{AHH}$ and $\underline{BHH}$, respectively, by $\underline{AH}$ and $\underline{BH}$, defined as the half-saturated complexes. The latter would substitute $\underline{AHH}$ and $\underline{BHH}$ in the breakdown reactions. Addition of a second hydrogen atom to $\underline{AH}$ and $\underline{BH}$ would constitute in each case an extra reaction step. Constant k would then be defined as the rate constant in both cases. The products of these extra steps, *viz.*, $\underline{AHH}$ and $\underline{BHH}$, would be considered as an adsorbed and undissociable saturated compound with properties identical in all respects. Since the saturated compound is very feebly adsorbed (5), its rate of release from the catalyst would be that at which $\underline{AHH}$ and $\underline{BHH}$ are formed. It can be seen how this scheme leads to the rate equations obtained in the previous one.

The introduction of function e^{at} in the rate equations was dictated by the necessity of obtaining relatively simple equations for the system composition and permitting the computation of rate constants to be

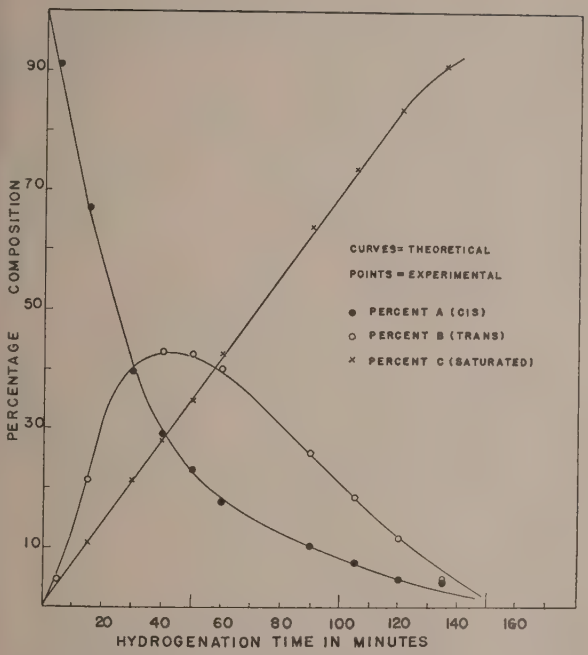

FIG. 2. Comparison of theory with experimental results obtained by Swicklik *et al.* for hydrogenation No. 2.

made readily. Its choice is justified by the good correlation resulting from the calculation of a series of a values with exclusive use of the data. Since function e^{at} is a mathematical aid, a has no mechanistic significance.

It must be pointed out that $1 + at$, the function used by Swicklik *et al.* to "correct" their initial postulate of first order reactions, is an approximation of e^{at}. As shown by their equation (7), these authors saw it as a modification of the rate constant interpreted as an increase with time of catalyst effectiveness. The present treatment shows clearly that the presence of such a function in the rate equations is the normal consequence of competition between the reactions leading to the formation of complexes. It is not required when the reaction medium is saturated with hydrogen. Hence Swicklik *et al.* found $a = 0$ in their experiment No. 1.

Table I shows some inconsistencies in the numeri-

cal values obtained by these authors. Their k_{02}/k_{03} ratio in experiment No. 2 indicates a higher reactivity for *trans* in opposition with the accepted view that *cis* is more reactive. This ratio is also appreciably different from that corresponding to experiment No. 3, although experimental conditions differed only in the pressure used. Note that the k_{02}/k_{03} ratios by our values are about equal and acceptable under the above criterion. The value obtained by Swicklik *et al.* for k_{03}, experiment No. 2, is questionable since by making $t = 0$ in their equation (8) one obtains,

$$dC/dt = 100\, k_{03}$$

leading to our own value for this constant.

On the other hand, their statement expressing that k_{01}/k_{04} should equal the *trans-cis* equilibrium ratio appears unwarranted in view of equation (22). It can be demonstrated, through the use of this equation and of relation (18), that k_{01}/k_{04} will only equal the equilibrium ratio in the unlikely event that $k_{02} = k_{03}$.

From relations (5) and (10)

$$k'_A/k'_B = k_{01}k_{02}/k_{03}k_{04}$$

The value of this ratio is 1.135 for experiment No. 2 and 1.04 for experiment No. 3, by our values. The rates of break-down for the complexes are thus approximately equal.

The method proposed for the computation of the constants is undoubtedly less tedious and more expeditive than one by trial and error. The value of k_C, that of the *trans-cis* equilibrium ratio, and those of A and B when B is maximum, constitute the only data needed for its application. A relatively small time lag and zero order kinetic conditions are a prerequisite however. Fortunately this is the general case when conditions similar to those used in industrial practice are used.

It should be noted that equation (22) suggests the occurrence of the *cis-trans* equilibrium described by Feuge *et al.*

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FURTHER IMPROVEMENT IN TROUT ANGLING AT CRECY LAKE, NEW BRUNSWICK, WITH PREDATOR CONTROL EXTENDED TO LARGE TROUT

by

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At Crecy Lake, Charlotte County, New Brunswick, hatchery-reared brook trout have been planted, the waters of the lake enriched with commercial fertilizers, and the control of trout enemies undertaken in attempts to improve the angling. Spawning conditions at Crecy Lake are poor. Planting was necessary to have a good supply of trout in the lake for testing fertilization and predator control. The results of these actions on the number and growth of trout taken by the anglers during the period from 1943 through 1953 have been fully discussed in previous publications (Smith, 1952a, 1955). However, the work at Crecy Lake has continued. This report gives results for two additional years, 1954 and 1955.

A guardian has resided at 50-acre Crecy Lake throughout each year. Planted hatchery-reared trout have been marked by fin-clipping. The trout captured by the anglers during each angling season have been counted and measured and examined for missing fins.

Summary of 1943-1953 Results

Poor catches of trout by the anglers from lakes of Charlotte County, New Brunswick, are associated with small quantities of plant foods in the waters. Planting hatchery-reared trout in these lakes has proved ineffective (Smith, 1952b). In 1946, commercial fertilizers (one ton of ammonium phosphate and 500 pounds of potassium chloride) were added to Crecy Lake in an attempt to raise its productive level and the yield of trout to anglers. The application amounted to 6·5 pounds of the fertilizers per acre-foot of water. An improved growth rate and survival of planted trout followed. Three-inch fingerling trout planted in September, 1946, grew to an average length of $8\frac{1}{2}$ inches by May and June, 1947. The improved growth rate continued through the next two years but survival sharply declined. Greater numbers of fish-eating birds and mammals (loon, osprey, kingfisher, otter and mink) appeared to be attracted to the lake by the annual planting of trout. Control of these predators, by killing or frightening them from the lake, was begun in August, 1949. Trapping of eels in the lake was begun in 1950. The survival of planted trout to the anglers' catches improved substantially; however, this was accompanied by a slower growth rate. These findings led to a second comparable fertilization in 1951. In order to utilize anticipated beneficial effects more fully the number of planted trout was

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doubled. As may be seen in Tables I and II, planting, fertilization and predator control in combination, but not singly, resulted in much better angling in Crecy Lake. The number of trout taken each year by the anglers rose from a low of 39 in 1949 to 3,276 in 1953. The rate of capture improved 9½ times.

Anglers' Catches Increase in 1954

Predator control was continued in 1954 on the same basis as before. The double rate of planting begun in 1951 was also continued in 1953. From these plantings, and from survivors of former plantings, the anglers took 4,074 trout from Crecy Lake in 1954--the highest number to that year (Table II). Also the rate of capture (2·6 trout per hour of fishing) was the best to that time. Although the survival of planted yearlings was unaccountably down from 1953, that of the planted fingerlings was improved (Table I). The growth of the planted fingerlings was somewhat less but as yearlings they were still acceptable to the anglers. The fingerlings planted in 1953 contributed 67 per cent by number and 43 per cent by weight to the anglers' catches in 1954. Since the average size of the trout was smaller, the yield by weight was less (by 5·2 pounds per acre) than in 1953. However, a greater proportion of the weight resulted from growth made by the trout in the lake after planting.

Further Increase in Catches in 1955 with Reduction in Numbers of Older Trout in the Lake

To 1954 the predator control involved fish-eating birds, mammals, and eels. Eels and large trout are the only fish in Crecy Lake that can eat small trout. If the number of larger trout in Crecy Lake were reduced, would a better survival of planted fingerlings result? It is more economical to plant fingerling than yearling trout, if by so doing good yields to the anglers can be maintained. In 1954 only fingerlings were planted. Also, 110 yearling trout were removed by gill-netting during late summer and early fall of 1954. Thus, predator control was extended to include older trout. The fingerlings planted in 1954 had about one-tenth the number of older trout as possible predators, as compared with the fingerlings introduced in 1953.

In 1955 the anglers took the largest number (5,623) of trout for any year during the entire study period (Table II). The rate of capture (3·2 trout per hour) was also the best during the investigation. This catch largely resulted from the remarkably high recovery of 41·4 per cent of the fingerlings planted in 1954 (Table I). Some fish from this planting, but an unknown number, still remain in the lake. This survival was twice as good as from any previous planting of fingerlings. Extension of predator control to the reduction in the number of older trout in the lake appeared to improve the survival rate of the planted fingerlings.

Is Predator Control Alone Sufficient?

Predator control was combined with other procedures in order to improve angling at Crecy Lake. Planting was necessary to provide a supply of trout. Fertilization improved the growth rate of the trout so that yearlings were of acceptable angling size. However, the effects of predator control on the angling were so striking as to

Table I

Growth and survival of planted trout in Crecy Lake.

Stock	Year of planting	Number planted	Average length* in inches when planted	Average length in inches when angled the following year	Percentage survival to anglers' catches
Yr.....	1944	675	11·5	14·4 (1946)	0·9
Yr.....	1945	812	7·5	10·1	10·1
Lake fertilized in June, 1946					
F.....	1946	6,701	3·2	8·5	4·3
Yr.....	1946	659	8·4	11·4	16·8
F.....	1947	6,684	2·9	9·3	0·8
Yr.....	1947	675	8·4	12·2	3·9
F.....	1948	6,575	2·4	8·4	0·4
Yr.....	1948	675	6·4	11·9	1·8
Predator control of fish-eating birds and mammals begun in August, 1949					
F.....	1949	6,750	2·6	7·5	1·9
Yr.....	1949	675	7·3	10·5	28·5
Trapping of eels in lake begun in June, 1950					
F.....	1950	6,750	3·3	6·7	19·8
Yr.....	1950	675	7·3	9·8	45·3
Second fertilization in June, 1951, and stocking rate doubled					
F.....	1951	14,160	3·2	6·8	11·7
Yr. (1)....	1951	674	10·1	10·4	81·9
Yr. (2)....	1951	675	7·0	8·7	36·2
F.....	1952	13,438	2·6	6·6	16·1
Yr. (1)....	1952	675	10·5	11·3	85·0
Yr. (2)....	1952	675	8·4	10·3	88·4
F.....	1953	13,390	2·9	6·1	22·0
Yr. (1)....	1953	675	9·8	10·3	79·4
Yr. (2)....	1953	675	7·8	8·5	55·9
F.....	1954	13,227	3·9	6·1	41·4**
No yearling trout planted and the number of older trout in the lake reduced by netting in 1954					

*Fork length.

**Survival to end of 1955 angling season; some trout from the 1954 planting still remain in the lake.

F.—Fingerlings; trout in their first year of life.

Yr.—Yearlings; trout in their second year of life.

Table II

Yield of trout to anglers from Crecy Lake

Year	1943	1944	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955
Number caught.....	166	148	139	425	110	39	264	1,441	2,418	3,276	4,074	5,623
Average number per rod-hour	0·5	0·5	0·6	1·0	0·3	0·2	0·6	1·4	1·6	1·9	2·6	3·2
Pounds per acre.....	2·2	1·5	1·4	3·6	1·6	0·9	2·9	6·4	11·4	18·1	12·9	10·7

suggest that worthwhile improvements in trout catches could follow its application alone on lakes. Improvement would, of course, depend upon having a suitable stock of native trout. Control measures should also be directed against any predacious fish that might be present.

Because of the small size of Crecy Lake and the presence there of a resident guardian, the control of fish-eating birds and mammals was thorough. Would a less complete control of these predators result in a reasonably good improvement in trout angling? Less control would be realized if a guardian were stationed on a large lake or if he patrolled a group of small lakes. Such modifications of predator control could be tested.

Acknowledgments

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Summary

Published results show that stocking, fertilization and predator control of fish-eating birds and mammals and the eel resulted in much improved fishing for brook trout in Crecy Lake, New Brunswick, during the period 1943-1953. Results are presented for 1954 and 1955. Predator control was continued. Of fingerlings and yearlings planted in 1953 anglers subsequently captured 22 and 68 per cent respectively. Predator control was extended to a reduction of older trout in the lake in 1954. Only fingerlings were planted. In 1955, the high survival of 41 per cent of these to the anglers' catches was realized, well illustrating the value of predator control.

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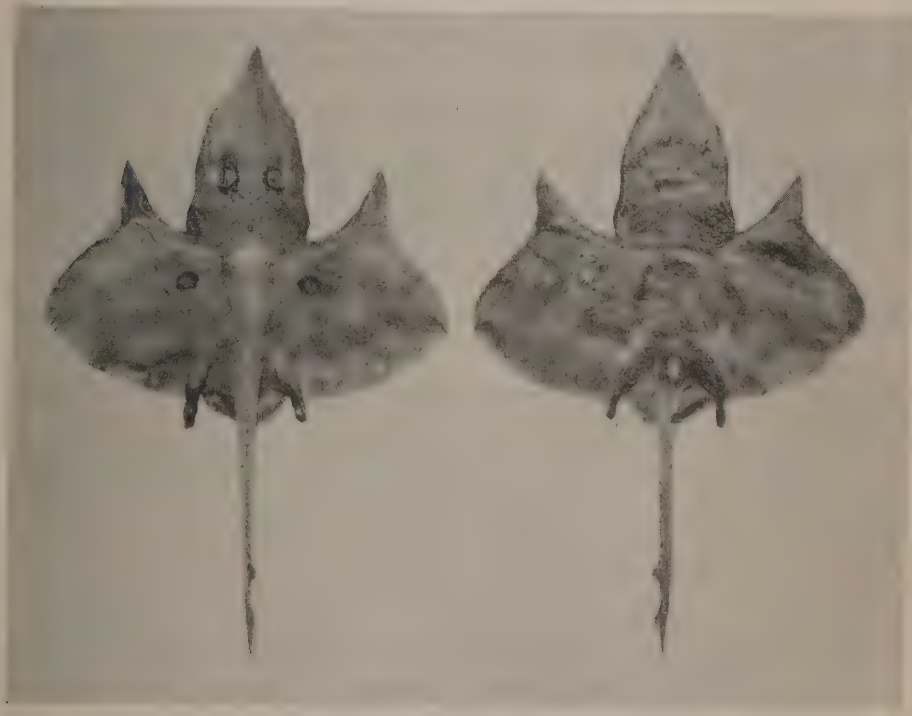
EDMOND CLOUTIER, C.M.G., O.A., D.S.P., Queen's Printer and Controller of Stationery, Ottawa, 1956.

AN ABNORMAL LONG-NOSED SKATE (*RAJA RHINA*) FROM BRITISH COLUMBIA

By W. E. Barraclough, Pacific Biological Station, Nanaimo, B.C.

An abnormal long-nosed skate (*Raja rhina*) was recovered by the otter trawler " Investigator No. 1 "* which was fishing at a depth of 40 fathoms in Stuart Channel on the east coast of Vancouver Island on November 16th, 1951. It readily attracted attention by its peculiar shape. The pectoral fins of this specimen, an immature male 230 mm. long, instead of being joined to the head region, projected forward freely on either side of the snout (*see* illustration).



Dorsal and ventral view of an abnormal long-nosed skate (*Raja rhina*).

Originally the descriptions of the genera *Cephaleutherus* (Rafinesque, 1810), *Propterygia* (Otto, 1821), and *Hieroptera* (Fleming, 1841) were based on teratologic specimens of rays and skates. It was first concluded by Gill (1895) that the abnormalities were conditioned by an arrested development in the forward growth of the pectoral fins and, consequently, in their continuity with the head.

Various degrees in the malformation or anterior prolongation of the pectoral fins have been illustrated and described. Dean (1923) credits Gesner (1556) with the first known account and figure of abnormal development of this type. The specimen illustrated by Traquair (1892) shows only a slight abnormal modification of the pectoral fins. Legendre (1935) shows photographs of arrested development of the pectoral fins

* The " Investigator No. 1 " is the research otter trawler at the Pacific Biological Station.

in *Raia brachyura,* which is very similar to the specimen of *Raja rhina* illustrated here. He cites many early references of abnormalities in rays and other elasmobranchs.

Williamson (1911) claimed that these abnormalities are the result of cutting by fishermen and advances reasons to suggest the possibility. Although fishermen will sometimes mutilate skates and dogfish in order to free the fish-hooks, it is unlikely that individuals with major abnormalities can be attributed to this form of mutilation, particularly symmetrical malformation of young individuals. Johnson (1905) suggests that the malformations are more nearly related to the primitive position of the elasmobranch pectoral-fin structures than to the position which the fins normally occupy in skates and rays.

The illustrations and description of the embryonic development of the skate *Raia brachyura* by Clark (1927) shows that the union of snout and pectorals is not complete until 111 days after fertilization of the egg. This irregular non-adherence of the pectoral fins to the head seems to be caused, as also suggested by Legendre, by stoppage of the growth processes producing this union and by independent extension of the pectorals in the region of the head.

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CATCHES OF FISH IN NEW BRUNSWICK STREAMS BY DIRECT CURRENT ELECTRO-FISHING

by

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During the course of an investigation of the inter-specific relationship of eels, *Anguilla bostoniensis* (LeSueur), and young Atlantic salmon, *Salmo salar* Linnaeus, in New Brunswick streams in 1952, direct current electrical fishing gear was used to collect fish in 12 screened-off sections of four salmon streams. The objectives of the project were to determine how many and what kinds of fish were present in each experimental section of stream, and, from stomach analyses of the eels that were captured, to discover what fish the eels had removed during a night's feeding (eels being mainly nocturnal foragers).

The present paper is limited to describing how fishing was carried out and what fish were captured. Some descriptions of observed differences in behaviour within the electric field and of differences in catchability of the more abundant species are also included. The intention of the paper is to present the data as examples of the use of the electro-fishing technique for the purpose of making fish population estimates in natural streams, and to demonstrate what success was achieved in collecting numbers of a variety of different kinds of fish. Readers are referred to Elson (1950), and Smith and Elson (1950), for more complete presentations of the use, the limitations and effectiveness, of similar electrical apparatus.

The electrical equipment used by the writer was like the Wolf machine and its accessories which Smith and Elson have described. The operator carried the positive electrode, which was connected to the gas-driven generator by a long cable of insulated wire. The negative electrode consisted of a small square of copper screening. It was attached to the generator by a short cable and was grounded on the river bottom. In this survey a new 1,000 watt D.C. generator was used. Its electrical output was much the same as the Wolf machine. In open circuit the speed of the motor was adjusted to maintain 750 volts. Under load, while fishing, the potential supplied and the current drawn varied from 600 to 700 volts and from 1·0 to 1·7 amperes in different waters. (Field equipment to measure the electrical conductivity of the waters was not available.)

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Method

Because of the need to obtain eels' stomachs after they had fed during the night, fishing was begun at first light, as soon as objects in the water could be seen clearly. Sections or sites were prepared on preceding evenings by setting barrier nets across their upper and lower limits. These nets were of ½-inch (stretched) cotton mesh, 6 feet wide and about 70 feet long. A foot-wide strip of burlap had been stitched along the bottom lines of each, and was buried under sand and gravel to seal the nets to the river bed. The nets were held upright and taut by posts set in the gravel.

A standard fishing procedure was followed at all sites, and for each "sweep" of a site. The operator with the positive or fishing electrode started at an upper corner of the site and fished slowly across the stream and back again, from bank to bank. He swept the electrode through the water, from as far as it would reach upstream to as far as it would reach downstream, then, lifting it from the water, repeated the movement. As necessary, and to ensure completeness of sweeping, the electrode was probed more diligently among stones and under overhanging banks. A few feet downstream from the operator stood two assistants. Each had a dip-net and one had a bucket of water to hold the captured fish alive. When returning across the stream the operator walked well within the strip of bottom just covered by the downward strokes of the electrode. Thus, every foot of the stream bed was thoroughly electro-fished. The term "sweep" refers to one complete fishing of a site in the manner described. Sweeps were immediately repeated at each site until the captures of each species during the last sweep were nil or a small fraction of the total taken in previous sweeps. The numbers of sweeps varied from two to four for each site.

Although frequently stunned by the shock, very few fish were killed by it. After fishing, all unwanted fish were returned to the water. They usually appeared to be in good condition. No attempt was made to capture the numerous very small fry of various minnows.

Some physical characteristics of the 12 fishing sites are listed in Table I.

Results

The total numbers of the several species of fish captured in each site have been listed in Table II.

From the 3,003 square yards of area making up the 12 fishing sites, 2,958 fish of 14 species were taken in 36 sweeps—four sweeps at three sites, three at six sites and two only at the remaining three sites. Species taken included black-nosed dace (*Rhinichthys atratulus*), salmon fry and salmon parr, eels, sculpin (*Cottus* sp.), brook trout adults and fry (*Salvelinus fontinalis*), burbot (*Lota lota*), and "other minnows". The salmon fry probably included both native and hatchery-reared fish, since numbers of the latter had been planted in some of these streams a month or so before the experiments. "Other minnows" include certain species which were numerically unimportant at most sites and have therefore been grouped under this heading. They include: northern creek chub (*Semotilus atromaculatus*), creek chub (*Couesius plumbeus*), shiners (*Notropis* sp.), sucker fry (*Catostomus* sp.), killifish (*Fundulus diaphanus*), pumpkinseed (*Lepomis gibbosus*) and sticklebacks (*Gasterosteus aculeatus* and *Pungitius pungitius*).

Table I

Dimensions and stream characteristics of the sites fished

Site	Length	Width	Area	Maximum depth	Mean depth	Bottom type	Water colour	Velocity	Temperature*
	ft.	ft.	sq. yd.	ft.	ft.			ft.–sec.	°C.
1. Digdeguash R.	91	34	344	2	1	D	medium	1·5	31
2. "	93	28	289	2	1	A	"	0·3	27
3. Becaguimic R.	61	41	278	3	1½	B	clear	3·0	20
4. "	90	30	300	2½	1	A—B	medium	1·1	25
5. "	81	10	90	1	½	B	"	1·5	20
6. Cold Stream	80	25	222	1½	½	A—B	clear	1·0	18
7. "	60	33	220	1	½	A—B	"	1·0	18
8. Shiktehawk R.	70	38	296	2	1	B	"	1·5	18
9. "	45	30	150	3	1½	C	"	2·5	19
10. "	60	37	247	2	1	C	"	1·4	19
11. "	80	37	329	3	2	B—C	"	1·0	19
12. "	63	34	238	1	½	C	"	1·6	17

A *Bottom even, gravel or stones over gravel; few or no large stones or boulders.*
B *Bottom even, round and flat, smooth stones; little gravel; few large stones or boulders.*
C *Bottom uneven, little gravel; many large stones and boulders.*
V *Bottom uneven, bedrock, and large stones and boulders; almost no gravel.*
* *Approximate mid-afternoon temperatures on day of fishing.*

Table II

Numbers of fish taken at the 12 sites.

Site	Eels	Salmon fry	Salmon parr	Black-nosed dace	Sculpin	Trout fry	Adult trout	Burbot	Other minnows	Totals
1. Digdeguash R.....	19	64	15	92	0	0	0	0	142	332
2. "	17	10	0	73	0	0	0	0	157	257
3. Becaguimic R.....	77	69	13	26	0	0	0	2	83	270
4. "	75	48	15	87	2	0	0	5	2	234
5. "	35	10	8	95	1	0	0	4	0	153
6. Cold Stream.....	3	219	35	70	161	2	0	11	9	510
8. "	14	49	12	45	23	33	1	0	0	177
8. Shiktehawk R.....	53	166	20	233	1	0	0	0	32	505
9. "	21	56	21	44	2	0	0	0	0	144
10. "	20	20	0	104	1	1	0	0	2	148
11. "	27	7	6	102	0	13	7	0	12	174
12. "	29	0	0	0	10	14	1	0	0	54
Totals.....	390	718	145	971	201	63	9	22	439	2,598

Tables III, IV, V and VI list, respectively, the numbers of "all fish", eels, salmon fry and black-nosed dace taken in each sweep at the nine sites where at least three sweeps were made. Data from sites where less than three sweeps were made are not included. In Table VII the catch-per-sweep of sculpin at two sites is given.

"All fish"

Table III shows that in nine sites a total of 2,264 fish was taken in the first three sweeps. The first sweeps took from 52 per cent to 80 per cent of the total catches made by three sweeps, with a mean value of 63 per cent.

Table III

Catch per sweep of "*all fish*" at nine sites.

Site No.	Sweeps				Totals	Sweep No. 1 per cent of total	Sweep No. 2 per cent of total	Sweep No. 3 per cent of total
	1	2	3	4*				
1	123	74	41	19	238	52	31	17
2	97	53	25	12	175	55	30	14
3	125	67	42	—	234	53	29	18
4	355	88	47	20	490	72	18	10
5	142	27	8	—	177	80	15	5
6	106	37	10	—	153	69	24	7
7	270	168	67	—	505	53	33	13
8	113	21	10	—	144	78	15	7
9	100	29	19	—	148	68	20	13
Totals	1,431	564	269	51	2,264	$\bar{x} = 63$	$\bar{x} = 25$	$\bar{x} = 12$

* *Not included in total catch.*

Eels

Eels were very responsive to D.C. electric stimuli (See Table IV.) When within the electrical field, they emerged from under stones and gravel, and made vigorous swimming movements towards the positive electrode. They were usually stunned, particularly the larger eels, when within a foot or so of the electrode. Their marked response appears to be related to their shape, since, as Fisher (1950) has stated, ". . . . in general the effectiveness of the electric current is directly related . . . . to the voltage drop from head to tail of each individual fish". Electrified eels were usually collected with ease, partly because of their marked response to the stimulus, and partly because their long, pale and twisting, bodies were easily visible in the water.

Table IV

Catch per sweep of "*eels*" at nine sites

Site No.	Sweeps				Totals	Sweep No. 1 per cent of total	Sweep No. 2 per cent of total	Sweep No. 3 per cent of total
	1	2	3	4*				
1	13	2	2	0	17	77	12	12
2	58	12	5	2	75	77	16	7
3	62	8	5	–	75	83	11	7
4	3	0	0	0	3	100	0	0
5	14	0	0	–	14	100	0	0
6	29	3	3	–	35	83	9	9
7	48	3	2	–	53	91	6	4
8	20	1	0	–	21	95	5	0
9	13	6	1	–	20	65	30	5
Totals	260	35	18	2	313	$\bar{x} = 83$	$\bar{x} = 11$	$\bar{x} = 6$

* *Not included in total catch.*

Salmon fry

Salmon fry exhibited a marked galvanotropic response by swimming up close to the positive electrode, and by following it vigorously through the water, as long as they were able, before being stunned. Within the electric field they were usually collected with ease, since, unless stunned, they remained well off the bottom. However, because they became paralysed only after severe exposure, they were sometimes able to escape the electric field, particularly if they received a shock near its periphery, or were frightened by movements of the operators. Other species such as black-nosed dace seemed to stun more easily than salmon fry, even though they were similar to the latter in size and in shape. Furthermore, the salmon fry did not school. They tended to move more freely and extensively about the stream, avoiding the movements of the fishing crew, and remaining outside the effective range of the electric field. Schooling species (black-nosed dace and other minnows) or bottom-dwelling species (eels and sculpins) were less active. Table V shows the catch per sweep of salmon fry at nine sites.

Table V

Catch per sweep of "*salmon fry*" at nine sites

Site No.	Sweeps				Totals	Sweep No. 1 per cent of total	Sweep No. 2 per cent of total	Sweep No. 3 per cent of total
	1	2	3	4*				
1	4	5	0	1	9	44	56	0
2	18	20	14	4	52	35	38	27
3	23	15	10	—	48	48	31	21
4	127	49	33	10	209	61	23	16
5	33	13	3	–	49	67	27	6
6	8	1	1	–	10	80	10	10
7	99	50	17	–	166	60	30	10
8	45	7	4	–	56	80	13	7
9	10	8	2	–	20	50	40	10
Totals	367	168	84	15	619	$\bar{x} = 59$	$\bar{x} = 27$	$\bar{x} = 14$

* *Not included in total catch.*

Black-nosed dace

The galvanotropic response of black-nosed dace, although quite evident, seemed to be much less pronounced than that of salmon fry. They seldom came close to the positive electrode, and only rarely followed its movements. They were usually stunned quickly when very close to the electrode, and then tended to drift into concealment among the stones. Retrieving them occasioned difficulty. However, at times the electrode could be brought suddenly among a school of dace, whereupon large numbers were caught quickly. This probably accounted in part for the apparent similarity in the catchability of these fish and salmon fry.

Table VI

Catch per sweep of "*black-nosed*" *dace* at nine sites

Site No.	Sweeps				Totals	Sweep No. 1 per cent of total	Sweep No. 2 per cent of total	Sweep No. 3 per cent of total
	1	2	3	4*				
1	28	17	18	10	63	44	27	29
2	12	8	3	3	23	52	35	13
3	30	39	18	–	87	34	45	21
4	65	3	1	1	69	94	4	2
5	42	3	0	–	45	93	7	0
6	59	30	6	–	95	62	31	6
7	94	104	35	–	233	40	45	15
8	31	10	3	–	44	70	23	7
9	74	14	16	–	104	71	13	15
Totals	435	228	100	14	763	$\bar{x}$ = 57	$\bar{x}$ = 30	$\bar{x}$ = 13

* *Not included in total catch.*

Sculpin

Two sites provided almost all the sculpins that were caught. The proportions taken in the first sweep suggest a high catchability, yet sculpin were difficult to capture. Their galvanotropic responses showed nothing unusual. They approached the electrode but usually remained on the bottom, seldom attempting to swim upwards towards it. Becoming stunned easily, they sank among the stones, where their mottled colouring made them difficult to detect. Their high rate of capture resulted in part from the extra effort expended to discover and collect them.

Table VII

Catch per sweep of *sculpin* at two sites

Site No.	Sweeps				Totals	Sweep No. 1 per cent of total	Sweep No. 2 per cent of total	Sweep No. 3 per cent of total
	1	2	3	4*				
4	110	31	13	7	154	71	20	8
5	17	3	3	–	23	74	13	13
Totals	127	34	16	7	177	$\bar{x}$ = 72	$\bar{x}$ = 19	$\bar{x}$ = 9

* *Not included in total catch.*

Other fishes

Altogether 63 trout fry were taken, 33 from one site. In the latter site the first sweep took 79 per cent of the total catch by three sweeps. Trout fry responses to the electrical stimulus appeared to be very similar to those of salmon fry, although their following of the electrode through the water was less pronounced.

A total of 145 salmon parr was caught in nine sites. These fish were taken often along the lower barrier nets, or among stones in its vicinity. When not able to avoid the electric field, they usually remained close to the electrode and followed its movements until captured, or until they were stunned from prolonged exposure.

Larvae (*Ammocoetes*) of the sea lamprey (*Petromyzon marinus*) were common in the mud of the banks at most sites. They were not collected. Although similar in shape and size to small eels, their galvanotropic behaviour seemed distinctly different. They were less affected by the electric current, for, although responding positively by rapid emergence from the mud, and swimming towards the electrode, they usually soon attempted, and frequently succeeded, in escaping the field.

Summary and Discussion

The combined area of the 12 experimental sites was 3,003 square yards, from which 2,958 fish, belonging to 14 different species, were taken. After thorough and repeated electro-fishing of each site, the total captures were considered to be close estimates of the total numbers of fish of each species present. In all instances, the final fishing of an area yielded only a small fraction of the total number of fish taken in the area.

The fish that were captured included species such as eels, sculpin and burbot, that are usually very difficult to capture with seines. The stream bottoms included types with many large boulders and overhanging banks that would have made seining a very inefficient means of capturing large proportions of the fish present. In these tests the type of stream bottom did not greatly affect the success of electro-fishing.

Because the main objective was the rapid capture of as many fish as possible, only incidental observations were made of apparent differences between species in their responses to the direct current stimulus. In general, fish that exhibited a marked galvanotropic response, such as eels particularly, and salmon fry, were collected most readily. However, as already explained, relatively high rates of capture were also obtained with apparently less responsive species, either by making use of their schooling behaviour (black-nosed dace), or by expending greater effort to retrieve affected fish (sculpin).

The success of the electro-fishing depended greatly upon the facts that all the experimental sections were shallow (between one and three feet in depth), and that the electrical conductivitity of the water was suitable for the apparatus in use, and provided a fairly wide electric field. Because the gear, including the barrier nets, weighed about 400 pounds, fishing sites were usually selected within a few hundred yards from road transportation.

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DESCRIPTION OF GENOLINEA ONCORHYNCHI N. SP. (TREMATODA: HEMIURIDAE) FROM ONCORHYNCHUS GORBUSCHA IN BRITISH COLUMBIA WITH NOTES ON THE GENUS[1]

By L. Margolis and James R. Adams[2]

Abstract

Genolinea oncorhynchi n. sp., parasitic in the stomach of *Oncorhynchus gorbuscha* (pink salmon) from British Columbia marine waters, is described and compared with other known members of *Genolinea*. Notes on host and geographical distribution of the genus are presented.

A survey of the parasites of Pacific salmon, genus *Oncorhynchus*, yielded two individuals of an apparently undescribed species of *Genolinea*. Both specimens were taken from the stomach of a juvenile pink salmon, *O. gorbuscha*. The host measured 80 mm. in fork length and had been in the sea for no more than three months. It was one of a group of 41 pink salmon examined from a beach seine catch at Alert Bay, Vancouver Island, British Columbia, on June 28, 1955. Three more young pink salmon taken at the same place on July 14 were free of this parasite. Also 50 *O. gorbuscha* with a similar period of marine residence taken at the Gnarled Islands, northern British Columbia on June 29 did not harbor this parasite.

Genolinea oncorhynchi n. sp.

(Figs. 1 and 2)

Of the two specimens one is mature with many eggs in the uterus and the other is young with only five eggs in the proximal portion of the uterus. The mature individual was studied from a ventral balsam mount and the younger specimen was mounted laterally. In the following description, measurements of the mature specimen are cited first, with measurements of the smaller individual placed in parentheses. All measurements are given in millimeters, except for the eggs, which are given in microns.

Description

The body is more or less cylindrical, having roughly the same diameter from the acetabulum to the broadly rounded posterior end. Anterior to the acetabulum it tapers gradually to a rounded anterior extremity. Body length is 0.745 (0.581) and the maximum breadth, at the level of the acetabulum, is 0.158 (0.130). The cuticle is smooth. The forebody is a little less than ½ body length. The oral sucker measures 0.06 in diameter (0.048 in length by 0.057 in width). The acetabulum lies 0.170 (0.116) behind the oral sucker

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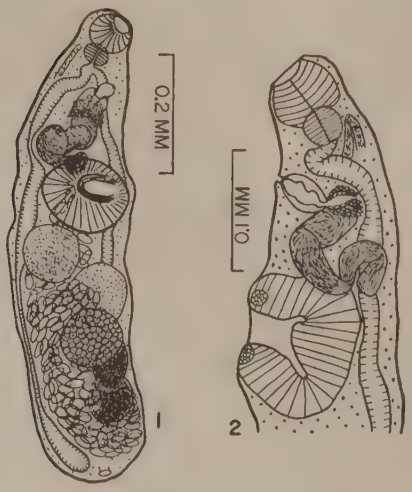

FIG. 1. Ventral view of mature specimen of *Genolinea oncorhynchi* n. sp.
FIG. 2. Lateral view of forebody of young specimen of *Genolinea oncorhynchi* n. sp. Note sphincter muscles in acetabulum.

and measures 0.124 (0.110) in diameter. Circular sphincter muscles are present in the acetabulum. The sucker ratio is about 1 : 2. The pharynx is broader than long, measuring 0.031 by 0.046 (0.030 by 0.037). The oesophagus is short and branches into two simple caeca that end blindly near the posterior end of the body.

The slightly oval, smooth testes lie obliquely lateral to one another just behind the acetabulum. The anterior testis measures 0.093 in length by 0.078 in width (0.085 in length by 0.062 in depth) and is situated to the right of the mid-line, barely extending anterior to the hind margin of the acetabulum. The posterior testis, measuring 0.108 in length by 0.093 in width (0.085 in length by 0.070 in depth), lies to the left of the mid-line and is more dorsally situated than the anterior one. The seminal vesicle is tubular, coiled, mainly preacetabular but arises a little behind the anterior edge of the acetabulum. Its maximum diameter is 0.047 (0.031). The short prostatic duct is largely dorsal to the base of the sinus sac and is completely surrounded by prostatic cells. In the smaller specimen it is a little less than $\frac{2}{3}$ the length of the sinus sac. The pars prostatica leads into a hermaphroditic duct which is enclosed in a muscular sinus sac. The hermaphroditic duct is protruding from the genital pore in the larger specimen and can apparently function as a copulatory organ. It is somewhat sinuous in lateral view of the smaller specimen. The ovoidal sinus sac, measuring 0.043 in width (0.043 in length by 0.031 in width), is directed obliquely dorsoventrally. The length of the sinus sac in the larger specimen could not be determined because the specimen is mounted ventrally. The ventral genital pore lies behind the intestinal bifurcation.

The globular ovary is situated mostly behind the testes but partially ventral to the posterior one. It measures 0.093 in diameter (0.073). The oval vitelline glands lie posterodorsal to the ovary, 0.093 (0.093) from the posterior extremity of the body. The anterior vitelline mass, measuring 0.078 in length by 0.047 in width (0.062 in length by 0.054 in depth), lies partially dorsal to the left portion of the ovary. The posterior vitelline mass, measuring 0.074 in length by 0.062 in width (0.050 in length by 0.047 in depth), slightly overlaps the anterior one. The seminal receptacle was not seen with certainty, but it appears to lie dorsal to the ovary. Mehlis' gland, apparent only in the smaller specimen, lies dorsal to the posterior vitelline gland. The uterus is mostly postacetabular. From its point of origin it passes posteriorly, dorsal to the vitellaria, to near the hind end of the body where it turns on itself and follows a sinuous course anteriorly, passing ventral to the left portion of the posterior vitellarium, dorsal to the ovary, ventral to the posterior testis, and dorsal to the anterior testis. The ova are 28–31 in length by 14–17 in width (28 by 14).

The excretory pore is subterminal. The main excretory vessels could not be seen in detail but it was noted, in the smaller specimen, that the anterior arms unite dorsal to the pharynx.

Type host: *Oncorhynchus gorbuscha* Walbaum (stomach)

Type locality: Alert Bay, British Columbia

Type specimens: The holotype (larger specimen) and paratype (smaller specimen) to be deposited in the National Museum, Ottawa, Canada.

Discussion

Yamaguti (12) lists seven species of *Genolinea* Manter, 1925, two of which originally had been allocated to other genera. *Brachyphallus anurus* Layman, 1930 was transferred to *Genolinea* by Yamaguti (11) and this same author (12) considered the genus *Parasterrhurus* Manter, 1934 synonymous with *Genolinea*. The type and apparently only species of *Parasterrhurus*, *Parasterrhurus anurus* Manter, 1934, became *Genolinea anura* (Manter, 1934). Since this specific name was pre-occupied by Layman's species, Yamaguti (12) proposed the new combination *Genolinea argentinae*.

Manter (9) described a new species, *Genolinea dactylopagri*, from New Zealand waters and presented a key to the six species which he recognized in the genus. He did not include *G. argentinae* and reduced *Genolinea robusta* Lloyd, 1938 to the synonymy of *Genolinea laticauda* Manter, 1925. Manter's (9) paper was completed before Yamaguti's (12) synopsis of the digenetic trematodes of fishes appeared and hence Manter's opinions on the proposed synonymy of *Parasterrhurus* with *Genolinea* are not recorded. However, in a later paper Manter (10, p. 75) implies that he has accepted this synonymy and notes that the genus consists of seven species. There are thus eight species of *Genolinea*, including the newly described one, known up to the present time. The eight species, with their synonyms, hosts, localities, and recording authors are listed in Table I.

TABLE I

LIST OF SPECIES OF *Genolinea* WITH HOSTS, LOCALITIES, AND AUTHORS

Species	Hosts	Localities	Authors
G. laticauda syn. *G. robusta*	*Hippoglossus hippoglossus*	Maine, U.S.A.	Manter (6, 7)
	Scorpaenichthys marmoratus	British Columbia	McFarlane (5)
	Scorpaenichthys marmoratus	Puget Sound, U.S.A.	Lloyd (4)
	Ophiodon elongatus	Puget Sound, U.S.A.	Lloyd (4)
G. aburame	*Hexagrammos otakii*	Inland Sea of Japan	Yamaguti (11)
G. anura syn. *B. anurus*	Cottidae, Hexagrammidae, and Pleuronectidae	Peter the Great Bay	Layman (2)
	Oncorhynchus gorbuscha	Amur River, U.S.S.R.	Layman (2, 3)
	Chironemus spectabilis	New Zealand	Manter (9)
G. manteri	*Leptocottus armatus*	Puget Sound, U.S.A.	Lloyd (4)
G. montereyensis	*Clinocottus analis*	California, U.S.A.	Annereaux (1)
G. argentinae syn. *P. anurus*	*Argentina striata*	Tortugas, Florida, U.S.A.	Manter (8)
G. dactylopagri	*Dactylopagrus macropterus*	New Zealand	Manter (9)
	Latridopsis ciliaris	New Zealand	Manter (9)
G. oncorhynchi	*Oncorhynchus gorbuscha*	British Columbia	Present paper

G. oncorhynchi n. sp. differs from the previously known species in body size (it is the smallest species) and in possessing relatively larger gonads with a more compact arrangement. The lengths of the testes and ovary are $\frac{1}{7}$ to $\frac{1}{8}$ of the total body length. It is distinct from all but *G. laticauda* in possessing sphincter muscles in the acetabulum.

The new species also differs from each of the previously described species as follows: from *G. laticauda* in that the acetabulum is more posteriorly located and the testes are less tandem and closer to the acetabulum; from *G. dactylopagri* in that the sucker ratio is smaller and the prostatic cells are less developed; from *Genolinea montereyensis* in that the acetabulum is more posteriorly located, the seminal vesicle is without sac-like expansions and the eggs are smaller; from *Genolinea aburame* in that the testes are closer to the acetabulum, the acetabulum is more posteriorly situated, the seminal vesicle is more coiled and lies farther forward in relation to the acetabulum, the sucker ratio is smaller, and the eggs are smaller; from *Genolinea manteri* and *G. anura* in that the testes are closer to the acetabulum, the forebody is longer with reference to total body length, the seminal vesicle is more anterior relative to the acetabulum, and from *G. manteri* only in that the eggs are smaller; from *G. argentinae* in that the sucker ratio is larger, the maximum body diameter is at the level of the acetabulum rather than posteriorly, the posterior extremity is rounded rather than truncated, and the testes are closer to the acetabulum.

G. oncorhynchi is the second species of the genus to be reported from *O. gorbuscha*. Layman (2, 3) recorded *G. anura* once from this same host taken in the Amur River. It was more commonly found in fishes of other families taken in Peter the Great Bay. The genus *Oncorhynchus* appears to be an uncommon or accidental host of *Genolinea* spp.

The genus *Genolinea* is known only from marine waters, where it occurs mainly in the stomach, but occasionally in the intestine and pyloric caeca of fishes.

From the data presented in Table I it is seen that *Genolinea* is a widespread genus, although it has not been recorded from European waters. Manter (10, p. 75) considers it a cold-water genus, emphasizing its bipolar distribution and occurrence only in the deeper and colder waters of tropical regions. The genus has been observed in the eastern and western North Pacific, in the northern American Atlantic, in New Zealand, and at Tortugas, Florida.

The host families of the six northern species are covered by the known hosts of one of the species. *G. anura* was originally described from Cottidae, Pleuronectidae, Hexagrammidae, and Salmonidae (genus *Oncorhynchus*). The hosts of the other five species are included in one or more of these families. At Tortugas the host is a member of the Argentinidae, a family very closely allied to the Salmonidae. In New Zealand, where two species of *Genolinea* (one of which is *G. anura*) have been reported, the hosts belong to three families of the superfamily Cirrhitoidae, which is included in the same order as the Cottidae and Hexagrammidae but in a different suborder. The Pleuronectidae and Salmonidae belong to two separate orders.

The foregoing discussion and the scarcity of *G. oncorhynchi* in *Oncorhynchus* suggests that the principal hosts of this trematode will ultimately prove to be local resident bottom dwelling fishes such as pleuronectids, cottids, etc., and that salmon are infected occasionally as a result of their short period of feeding in inshore waters.

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The Kinetics of the Hydrogenation of Pure Fatty Esters. III. Poly-Olefinic Systems: Selectivity of Raney Nickel

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THE PRESENT WORK was undertaken to determine the selectivity displayed by Raney nickel catalysts in the hydrogenation of polyunsaturated fatty esters.

Preliminary work of a semi-quantitative nature had indicated a definite influence of the preparative technique on this property. This was evident from estimations of the relative reactivity of the double bonds of methyl linoleate toward hydrogen in the presence of several Raney nickel preparations. Such determinations can be made by computing the data obtained from the complete analysis of samples from the hydrogenation reaction mixture at timed intervals, a method first used by Bailey (2) with vegetable oils and commercial-type nickel catalysts. This procedure involves a considerable amount of analytical work however, even when the starting material is a simple glyceride or monoester.

A very satisfactory method was found when it was observed that the absorption rate data obtained on hydrogenating methyl linoleate under certain conditions were directly interpretable. This was not surprising since these conditions, *i.e.*, hydrogenation at room temperature in a medium kept saturated with hydrogen, had proved in our work on methyl oleate (7) to be conducive to very simple kinetics; no complicating effect could be detected from *cis-trans* isomerization or double bond shifts, and first order kinetics were obtained throughout. In the case of polyunsaturated esters one could expect under the same

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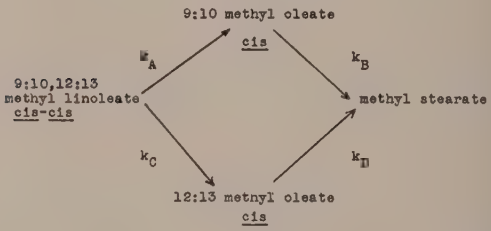
conditions the saturation of each particular double bond to proceed at a rate defined by

$$R_U = k_U U \qquad \text{I}$$

where U is the concentration in the medium of the molecular species bearing that particular double bond and k_U a specific constant. A general mechanism for the hydrogenation of *cis-cis* methyl linoleate would then be described by the following system involving two simultaneous routes, each including two consecutive reactions of the first order:



II

Equations giving for any given time the hydrogen H to be absorbed for complete saturation, and R, the hydrogen absorption rate, can be derived from the above mechanism. In these equations, specific constants k_A, k_B, k_C, and k_D are unknown parameters. Since H and R can be obtained by direct measurement (8), values for the constants should be directly computable from absorption data. Such data were obtained from more than 200 hydrogenation experiments, in which the ratio of ester to catalyst and the catalyst itself were the only variables.[1]

Experimental

Materials and Methods. The preparation and properties of *methyl oleate* and *95% ethyl alcohol* have been described in Part I of this series (7). *Methyl linoleate* was derived from highly purified tetrabromostearic acid (mp. 115°) by debromination followed by esterification and molecular distillation. This ester did not contain any conjugated material detectable by alkali-isomerization techniques (3).

The small amount of *trans* isomer that linoleate obtained by debromination is known to contain did not appear to interfere in the present work. Storage

[1] Most of the experiments were carried out under the author's direct supervision by J. D. Nickerson (Dalhousie University, M.Sc. Thesis, 1950), and A. B. Cann (Acadia University, M.Sc. Thesis, 1951).

and handling procedures were the same as for methyl oleate. I. V.: 172.5, theoretical: 172.3; hydrogenation value (8): 1.370, theoretical: 1.370; n_D^{20}: 1.4613, reported: 1.4611 (5), 1.4616 (4), 1.4613 (6).

Catalysts. These were prepared through various modifications of the procedure described by Adkins and Billica (1) for the preparation of W 5. They were stored under 95% alcohol in the refrigerator between uses. Some were kept under a blanket of hydrogen, some under nitrogen; for others no protecting blanket was used. Samples were pipetted from thoroughly mechanically-stirred suspensions while bubbling with either nitrogen or hydrogen when these gases were used for blanketing. The exact amount of catalyst used was determined by nickel estimation in the recovered catalyst.

Apparatus and Hydrogenation Procedure. All experiments were carried out in the precision semimicro hydrogenator described in a previous paper (8), using 95% ethyl alcohol as solvent (17 ml.), at 25.00°C. and under 760.0-mm. Hg pressure. Readings were taken every minute.

Determination of Absorption Rate Curves. The rate R_i at minute i was taken as half the volume change observed between minute $i-1$ and minute $i+1$.

Rates were plotted against H_i defined as the volume change from minute i until the system was completely saturated. H_i is an expression of the concentration of unreduced double bonds provided the sample were completely dissolved.

A Mathematical Expression of the Data. All absorption rate curves displayed the characteristics shown by the experimental curve in Figure 1. Branch AB of this curve reflects the marked lag affecting the first experimental points, as in the case of methyl oleate discussed in Part I of this series.

A little more than one minute usually elapsed from the time the sample was dropped into the stirred alcohol-catalyst mixture to the moment when the sample was completely dissolved and the catalyst had reached full activity. The first two readings corresponded to this non-ideal state of the system. The first two values of H_i and the first three values of R_i calculated from them are in error. From then on (Point B on the curve) the relationship between H_i and R_i was normal.

Branch BC, which is almost a straight line, is joined to DO, a line straight to the origin, by a

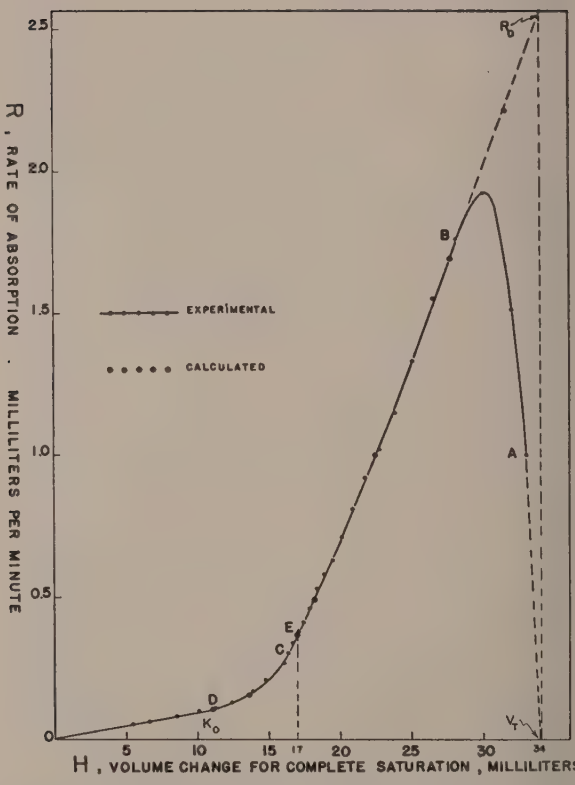


FIG. 1. Typical absorption rate curve obtained with methyl linoleate. Comparison between experimental and calculated values.

curved section CD. The latter is located somewhat beyond E, the point corresponding to the absorption of half the theoretical amount of hydrogen. The above features are suggestive of a system of two consecutive reactions of the first order such as described by:

$$\text{Me. linoleate} \xrightarrow{k_L} \text{Me. oleate} \xrightarrow{k_O} \text{Me. stearate} \quad \text{III}$$

where k_L and k_O are velocity constants with k_L much larger than k_O. This system is a particular case arising from the general system II when only one route is followed by the reaction or, alternatively, when $k_A = k_C$ and $k_B = k_D$ simultaneously.

It is described by the following differential equations:

$$dL/dt = -k_L L$$

and

$$dO/dt = k_L L - k_O O$$

where L and O are, respectively, the amounts of linoleate (moles) and oleate in the reaction mixture.

The solutions to these differential equations are given by:

$$L = L_T e^{-k_L t} \qquad \text{IV}$$

$$O = k_L L_T (k_L - k_O)^{-1} (e^{-k_O t} - e^{-k_L t}) \qquad \text{V}$$

where L_T is the original amount of linoleate.

Let H_L be the volume change observed in the burette when one double bond is saturated in L moles of linoleate; let H_O be the volume change corresponding to the saturation of O moles of oleate. The change corresponding to the half saturation of L_T moles of linoleate is $V_T/2$, V_T being the volume change observed upon complete saturation of the sample.

Since in each case the hydrogen consumed corresponds mole for mole to the ester involved,

$$H_L/L = H_O/O = V_T/2L_T$$

It follows that L, O, and L_T can be substituted respectively by H_L, H_O, and $V_T/2$ in equations IV and V. Hence,

$$H_L = 2^{-1} V_T e^{-k_L t} \qquad \text{VI}$$

$$H_O = 2^{-1} k_L V_T (k_L - k_O)^{-1} (e^{-k_O t} - e^{-k_L t}) \qquad \text{VII}$$

The sum $2H_L + H_O$ is equal to H; the volume change corresponds to the complete saturation of the system. Thus

$$H = 2^{-1} V_T (k_L - k_O)^{-1} [(k_L - 2k_O) e^{-k_L t} + k_L e^{-k_O t}] \qquad \text{VIII}$$

The rate at which the hydrogen is consumed, $-dH/dt$, is R, the rate of absorption. Deriving $-H$:

$$R = 2^{-1} k_L V_T (k_L - k_O)^{-1} [e^{-k_L t} (k_L - 2k_O) + k_O e^{-k_O t}] \qquad \text{IX}$$

Values for R and H have been determined experimentally for every minute of the reaction. It should be possible therefore to determine k_O and k_L by trial and error, using VIII and IX to compute the data. One complication is that all experimental time values are affected by the same lag error (beyond point B of the curve), which is one more parameter to be determined. To avoid time-consuming computations, the following methods have been used.

Determination of k_O. Since k_L is much larger than k_O, $e^{-k_L t}$ will much sooner assume insignificant values

than $e^{-k_O t}$ with increasing time values. Making $e^{-k_L t} = O$ in VIII and IX, and combining the results, one obtains:

$$R = k_O H \qquad X$$

indicating that the absorption curve should assume, as it does, the form of a straight line towards the end of the reaction. Moreover X indicates a very simple way of finding k_O as the slope of branch DO.

Determination of k_L. Making $t = O$ in IX yields an expression of R_O, the initial rate:

$$R_O = k_L V_T/2 \qquad XI$$

which suggests determining k_L from the value of R_O. Unfortunately R_O cannot be determined with precision because the first experimental points are unreliable.

The following expression was derived from VIII and IX:

$$k_L = [R_1 E - R_2](H_1 E - H_2)^{-1} \qquad XII$$

with $E = exp. - k_O(t_2 - t_1)$

It involves k_O, which can be determined from the curve, and two sets of experimental values t_1, R_1, H_1 and t_2, R_2, H_2. When both sets of values are selected from data corresponding to points beyond branch AB of the curve, both t_1 and t_2 are affected by the same lag error; expression XII, which contains their difference, $t_2 - t_1$, is then true regardless of the lag. With XII any paired combination of the numerous t_i, R_i, H_i sets of values obtained in the course of an experiment can be used.

The validity of equations VIII and IX and therefore of the postulate described by III was established by applying the above methods of analysis to the considerable data which had been obtained.

Application of expression XII to several pairs of experimental H_i, R_i, t_i values corresponding to all sections of the curve, save AB, gave the results shown in Table I.

Both numerator and denominator values in XII result from differences which tend to magnify errors several times. The good correlation obtained is thus highly significant; it is also an indication of the precision attainable with the hydrogenator used. Further proof for the system postulated is shown in Figure 1, where calculated values of H and R have been plotted.

As was to be expected, these points fall on the experimental curve while experimental H and R values

TABLE I

Calculation of k_L, Using Equation XII[a]
$k_L = [R_1E - R_2](H_1E - H_2)^{-1}$ with $E = exp. - ko(t_2 - t_1)$,
$ko = 0.01$, d = % deviation from average.

t_1	t_2	E	H_1E	R_1E	H_2	R_2	k_L	d
5	15	0.905	23.97	1.405	17.84	0.46	0.154	+2
6	16	0.905	22.70	1.205	17.41	0.41	0.151	0
7	17	0.905	21.55	1.040	17.02	0.38	0.145	−4
8	18	0.905	20.60	0.923	16.66	0.34	0.148	−2
9	19	0.905	19.70	0.832	16.34	0.30	0.158	+4.6
10	20	0.905	18.95	0.733	16.05	0.27	0.159	+5.3
15	25	0.905	16.15	0.416	14.80	0.21	0.152	+0.6
5	25	0.819	21.70	1.270	14.80	0.21	0.153	+1.3
10	30	0.819	17.15	0.663	13.85	0.17	0.149	−1.3
10	50	0.67	14.05	0.542	11.20	0.11	0.152	+0.6
10	100	0.407	8.51	0.329	6.66	0.066	0.142	−6.0
						Average k_L	0.151	

[a] The H_1, R_1, and t_1 data correspond to the experiment described by the curve in Figure 1.

do not correspond to calculated ones for the same time value. The lag accounting for the discrepancy is easily determined from a plot against time of a few experimental and calculated values of H. In this case the lag was 1.25 min.

The determination of an approximate value for k_L from the extrapolated value of R_O is only feasible when, as in the example given, the number of points on the BC branch is large. When the reaction time is short relatively few points are obtained on BC and branch AB assumes considerable importance. Equation XII is then particularly useful.

It must be pointed out that it is only necessary to reach point D in order to apply the above methods and that the operation need not be pursued as far as shown in the above example. In many experiments point D was reached in 30 min. The total volume change V_T corresponding to complete saturation of the sample is then calculated from the weight of material used. For 100 mg. of methyl linoleate in 95% ethyl alcohol, $V_T = 18.05$ ml. at 25°C., under 760 mm. Hg.

It must be pointed out that H_1, R_1, and V_T represent volumes of hydrogen saturated with alcohol vapor. The partial pressure of ethyl alcohol at 25°C. is 59 mm. Hg, and the actual volumes of hydrogen are found by multiplying H_1, R_1, and V_T by 701/760.

Results and Discussion

In Part I of this series

$$k_O = GJFDMRH\,(1 + RH)^2$$

gave the slope k_O of the straight line obtained for the absorption rate curve with methyl oleate hydro-

genated under the conditions used in the present work. In this expression D represents the total area of the catalyst. Slope k_O, also that of OD in the curve obtained for methyl linoleate, should be proportional to the amount of catalyst used when this amount is the only factor made to vary. This is assuming that the area per unit weight of catalyst is uniform throughout the batch and that the activity does not vary on aging. If Ni designates the nickel content of a sample of Raney nickel, successive hydrogenations of the same amount of methyl oleate, or linoleate, should result in a constant k_O/Ni ratio. Furthermore the ratio should be the same for both esters if the postulate described by III is true.

A study of k_O/Ni ratios showed that all the Raney nickel used aged rapidly. This introduced a difficulty in comparing ratios for the two esters. It was surmounted satisfactorily by alternating hydrogenations of each ester as quickly as possible and by averaging the ratios obtained in both series. Table II shows these averages to be indeed approximately equal.

TABLE II

Comparison Between ko/Ni Ratios for Methyl Oleate and Methyl Linoleate

Age, days	Methyl oleate (200 mg.)				Methyl linoleate (199 mg.)			
	Run No.[a]	Ni (mg.)	ko $\times 10^3$	ko/Ni $\times 10^6$	Run No.[a]	Ni (mg.)	ko $\times 10^3$	ko/Ni $\times 10^6$
50	1	101.3	61.0	602	2	105.4	65.5	622
50	4	109.7	64.5	588	3	107.6	53.5	576
70	6	110.0	57.5	521	5	115.3	53.5	538
70	7	103.7	56.0	541	8	103.6	50.0	521
81	9	111.2	56.0	504	10	113.7	55.0	484
81	12	111.7	57.0	510	11	115.8	59.0	510
90	14	127.0	62.0	488	13	120.2	56.5	470
90	15	135.3	57.0	421	16	119.4	52.5	440
	$10^6 \times$ko/Ni, average 521				$10^6 \times$ko/Ni, average 519			

[a] Runs were carried out in the sequence indicated by run numbers.

Table II also illustrates other difficulties encountered in dealing with Raney nickel suspensions. Although the same pipette was used and the suspension was vigorously stirred in all cases, the amount of catalyst pipetted varied appreciably. Furthermore the variation in activity observed on consecutive runs could not always be accounted for by aging. Both types of variation must result from lack of homogeneity.

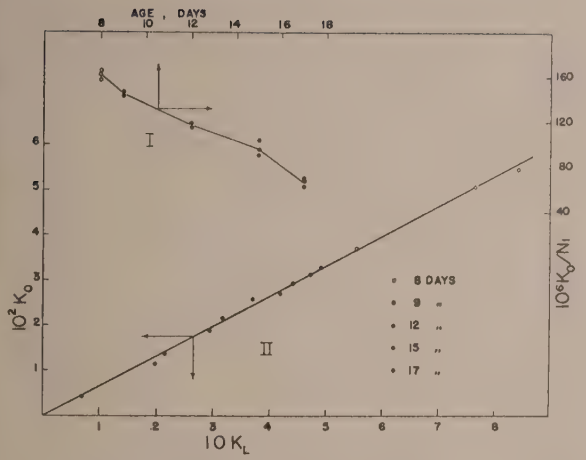


FIG. 2. Plot I. Decline of catalytical activity k_0/Ni on aging. Plot II. Constancy of selectivity index k_L/k_0.

In the case just described, catalyst aging had been retarded purposely by storing it under hydrogen. When no protective blanketing was used, the activity, as indicated by k_0/Ni ratios, fell much more rapidly. This is shown by plot I, Figure 2, for 13 successive hydrogenations carried out over a 9-day period, in the course of which the activity declined to about one-third its original value. Rather surprisingly, the k_L/k_0 ratio remained remarkably constant as evidenced by plot II, Figure 2, of k_0 against k_L values obtained from the corresponding data.

Constancy of the selectivity index defined by k_L/k_0 was observed in all cases. It is independent of aging and of lack of homogeneity. A study of the selectivity of Raney nickel catalysts in relation to preparative conditions was thus possible.

It would seem that the present method of investigation is well suited to study such effects. Values of k_L/k_0 can be obtained within an hour at little expense of work or material.

The above results do not give any clue as to what alternative route the reaction is taking or whether the two routes are followed simultaneously at an equal rate. A chromatographic study of oxidative material (point D on the absorption curve, Figure 1) gives the answer to this problem. It will be published at a later date.

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The Status of the Major Herring Stocks in British Columbia in 1955-56

BY

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THE STATUS OF THE MAJOR HERRING STOCKS IN BRITISH COLUMBIA IN 1955–56

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INTRODUCTION

The status of the major aspects of the herring research carried out at the Biological Station, Nanaimo, B.C., by the Fisheries Research Board of Canada is reviewed annually in these reports. During the period from 1946–47 to 1951–52 the results of a detailed study of the effects of a virtually unrestricted fishery on the herring stocks on the west coast of Vancouver Island were presented, along with such data on other stocks as were pertinent to this problem (Tester and Stevenson, 1947, 1948; Stevenson, 1950; Stevenson and Lanigan, 1950; Stevenson, Hourston, and Lanigan, 1951; Stevenson, Hourston, Jackson, and Outram, 1952). The comparative nature of this study was stressed in the next two reports, which treated the west coast and lower east coast of Vancouver Island stocks with equal detail (Stevenson and Outram, 1953; Taylor and Outram, 1954). With the termination of this experiment, attention was again focused on the coast as a whole, and the 1954–55 report (Taylor, 1955) included an analysis of all the major herring stocks on the British Columbia coast. The inclusion in this report of data from a study of the abundance and nature of the stocks of juvenile (1-year) herring provides complete coverage of the current herring research for the first time.

The results of the study to date have indicated that certain sub-districts (west coast of Vancouver Island, central, and Queen Charlotte Islands) contain more than one population, and these have been split to expand the number of sub-districts to ten (Fig. 1).

In the following report, the sections on the fishery and adult tagging and tag recovery were prepared by the senior author, who is in charge of the research programme. Outram provided the section on extent and intensity of spawning. The remaining sections were written by Hourston.

THE 1955–56 FISHERY

The phenomenally high catch in the lower Queen Charlotte Islands and good catches in the lower central and middle and lower east coast of Vancouver Island sub-districts were mainly responsible for the record catch of 250,444 tons of herring taken in 1955–56 (Morgan, MS.). Catches in the northern, upper central, upper east coast of Vancouver Island and upper west coast of Vancouver Island were poor. The table below shows for each sub-district the catch and catch per unit of effort in 1955–56 and in the previous season, and the average catch from 1951–52 to 1955–56.

Sub-district	Catch, 1955–56	Catch, 1954–55	Average Catch, 1951–52 to 1955–56[1]	Catch per Unit of Effort, 1955–56	Catch per Unit of Effort, 1954–55
Upper Queen Charlotte Islands[2] (2A (E))	6,458	21,800	13,715	58	75
Lower Queen Charlotte Islands[2] (2B (E))	85,609	550	24,827	138	76
Northern	11,429	20,050	29,632	22	51
Upper central[2]	1,869	9,700	9,218	—	22
Lower central[2]	46,391	17,850	27,620	98	32
Upper east coast of Vancouver Island	920	9,200	6,255	46	82
Middle east coast of Vancouver Island	29,652	24,650	21,062	47	40
Lower east coast of Vancouver Island	48,709	51,300	48,418	59	56
Lower west coast of Vancouver Island[2]	18,847	6,863	17,281	88	18
Upper west coast of Vancouver Island[2]	560	7,200	8,925	62	61
Totals (tons)	250,444	169,163	206,953	—	—

[1] Catches in 1952–53 were omitted.

[2] Changes in terminology are discussed in section on Age Composition.

The catch in the upper Queen Charlotte Islands sub-district (Area 2B (E)) in 1955-56 was the largest ever caught in a single area. Between February 5th and March 9th a total of 85,609 tons were taken from the Burnaby Narrows-Huxley Island region. Availability declined from 251 tons per seine-day in the first week to 178 tons per seine-day in the second week, and levelled off at the relatively high level of between 112 and 126 tons per seine-day for the remaining three weeks. On the other hand, fishing in the lower Queen Charlotte Islands sub-district (Area 2A (E)) was poor in 1955–56. The catch (6,458 tons) was less than one-third of the 1954–55 catch. Availability decreased sharply during the fishery from 96 tons per seine-day in the third week in January to 9 tons per seine-day two weeks later. The fishery was closed on February 1st because of the large proportion of small fish present.

In the northern sub-district (Areas 3, 4, and 5), the quota was not taken for the second successive year. The catch, the smallest since 1946–47, was little more than one-half of the 1954–55 catch. The fishery centred in Morse Basin, with Tuck Inlet and Prince Rupert Harbour providing small catches. It would appear that the 1955–56 fishery was dependent on local resident stocks, and that the main migrating population usually fished in Edye Pass, Ogden Channel, and Kitkatlah Inlet did not become available to the fishery in 1955–56. There were reports of a large body of herring off Porcher Island during the season, which might have represented at least part of this population, but these fish were inaccessible to the fishery. This supposition receives some support from the 1956 spawn survey. Although spawning was slightly less than in 1955, it was not below the average for recent years. The decrease occurred in Area 5, while spawning in Areas 3 and 4 showed slight increases.

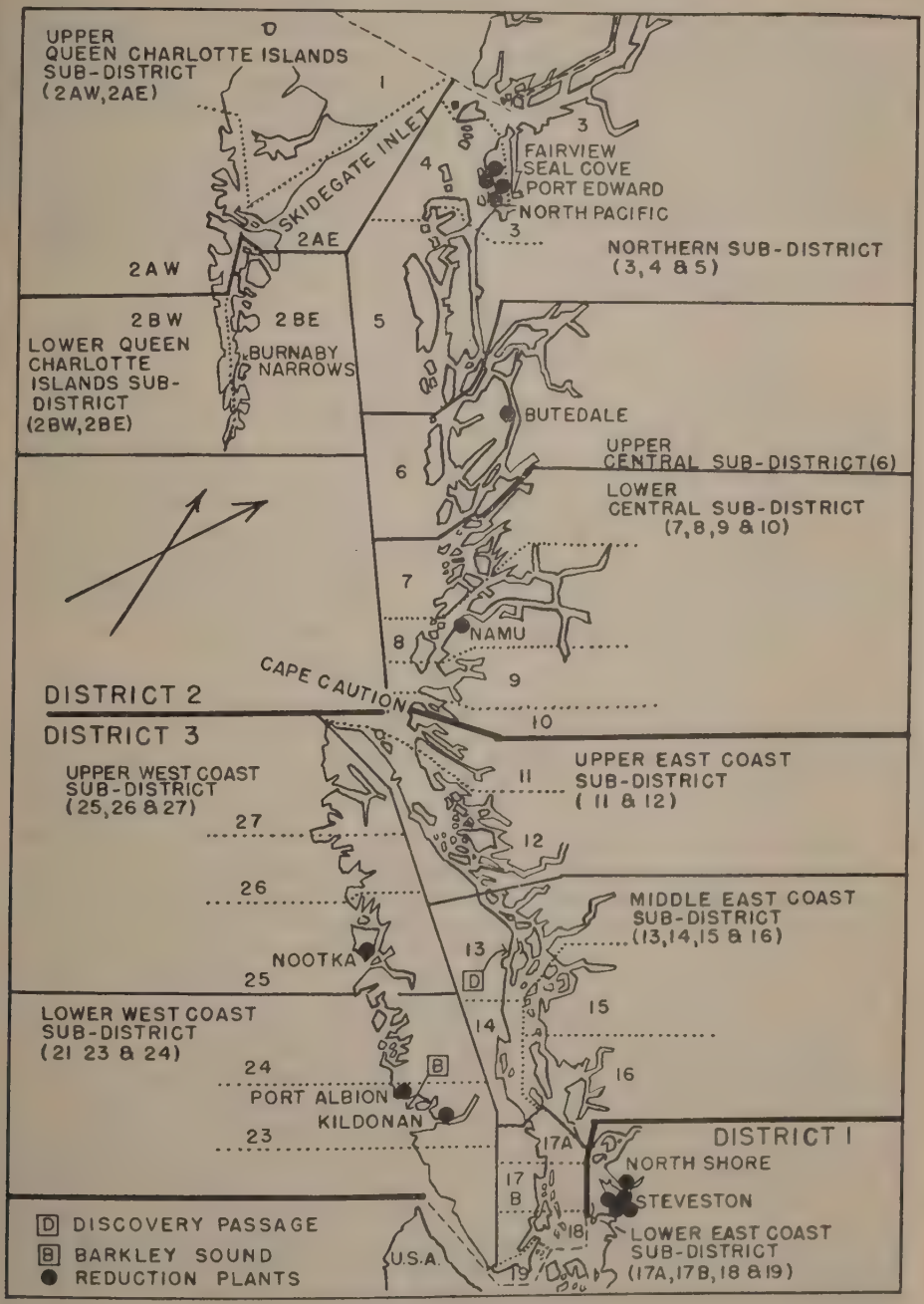
The catch in the upper central sub-district (Area 6) declined sharply from the 1954–55 level, which was average for the past five years. A small fishery developed in Thistle Passage and Laredo Passage, but poor availability, combined with good fishing in the neighbouring lower central sub-district, resulted in the poorest catch from the upper central sub-district since 1943–44.

The lower central sub-district (Areas 7, 8, 9, and 10), in contrast to the previous two seasons, supported an excellent fishery. The 1955–56 catch was exceeded only by those made in 1950–51 and 1948–49; it came almost entirely from Area 7. Availability was 98 tons per seine-day, treble that of the previous season. In the peak fishing period during the two weeks immediately prior to the pre-Christmas closure it reached 266 tons per seine-day. During this period over half the catch was taken. Insignificant catches were made in Areas 8 and 9, and there was no fishery in Area 10.

In the upper east coast sub-district (Areas 11 and 12) the catch was the lowest on record, one-tenth that of the previous season.

In the middle east coast sub-district (Areas 13, 14, 15, and 16) a record catch of 29,652 tons was made. Of this total, 17,916 tons was taken in Area 13 and 11,735 tons in Area 14. The main fishery developed after the Christmas closure. The quota of 10,000 tons was taken by January 13th, followed with a quota extension of 10,000 tons taken by January 28th, and a second extension of 10,000 tons taken by February 10th as a result of a five-day extension of the season. Availability in the sub-district as a whole was about the same as in previous years; it was somewhat greater in the post-Christmas than in the pre-Christmas period and was slightly greater in Area 14 than in Area 13.

The catch in the lower east coast sub-district (Areas 17A, 17B, 18, and 19), while high, was slightly less than in the previous two seasons. Fishing commenced approximately a month later than in 1954–55, and although the original 40,000-ton quota was again taken in three weeks, a 10,000-ton extension granted on December 6th was not filled by the time of the Christmas closure. After Christmas, only desultory fishing occurred as the fleet dispersed to other sub-districts. Availability was similar to that in 1954–55 but less than that in 1953–54.


UPPER QUEEN CHARLOTTE ISLANDS SUB-DISTRICT (2AW,2AE)
SKIDEGATE INLET
2AE
2AW
2BW
2BE
LOWER QUEEN CHARLOTTE ISLANDS SUB-DISTRICT (2BW,2BE)
BURNABY NARROWS
FAIRVIEW
SEAL COVE
PORT EDWARD
NORTH PACIFIC
NORTHERN SUB-DISTRICT (3,4 & 5)
BUTEDALE
UPPER CENTRAL SUB-DISTRICT (6)
LOWER CENTRAL SUB-DISTRICT (7,8,9 & 10)
NAMU
CAPE CAUTION
DISTRICT 2
DISTRICT 3
UPPER WEST COAST SUB-DISTRICT (25,26 & 27)
UPPER EAST COAST SUB-DISTRICT (11 & 12)
MIDDLE EAST COAST SUB-DISTRICT (13,14,15 & 16)
NOOTKA
LOWER WEST COAST SUB-DISTRICT (21 23 & 24)
PORT ALBION
KILDONAN
DISTRICT 1
NORTH SHORE
STEVESTON
LOWER EAST COAST SUB-DISTRICT (17A,17B,18 & 19)
U.S.A.
D DISCOVERY PASSAGE
B BARKLEY SOUND
REDUCTION PLANTS

In the lower west coast sub-district (Areas 21, 23, and 24), the only region in which a major fishery developed was Barkley Sound (Area 23). Here a catch of 18,160 tons was made, 16,877 tons being caught in December prior to the Christmas closure. This is almost three times the catch made here in 1954–55. Availability for the season as a whole was 89 tons per seine-day, compared to 18 tons per seine-day in 1954–55. Area 24 produced a catch of only 685 tons.

In the upper west coast sub-district (Areas 25, 26, and 27) only 560 tons were taken, all from Area 26. No fishery developed in Area 27, and for the second successive year no catches were made in Area 25. As spawn deposition in Area 25 was at a high level in 1956, late inshore migration rather than a lack of abundance of herring may have been responsible for the absence of a fishery in Area 25.

TAGGING

Tagging of Adult Herring

In 1955 the emphasis of the adult tagging programme was transferred from assessing the degree of intermingling between the major herring populations on the British Columbia coast to determining more accurately the complex relationships existing between the middle and lower east coast of Vancouver Island populations. In the spring of 1956, tagging in British Columbia waters was again confined to these two Strait of Georgia populations. A total of 15,535 tags were inserted (Table I), using the same methods as employed in previous years (Tester and Stevenson, 1947). The numbers of fish tagged in the various areas in 1955 and in 1956 are summarized below:—

Year	Sub-district and Area of Tagging							Total
	Middle East Coast				Lower East Coast			
	13	14	15	16	17A	17B	18	
1955	1,500	2,953	3,020		3,025	5,509	1,498	17,505
1956	1,529	6,713	——	1,518	1,249	3,008	1,518	15,535

In recent years, recoveries have been made in the Canadian fishery from taggings carried out by the State of Washington Department of Fisheries in the San Juan Islands and Puget Sound regions. Information on these taggings is given in the table below:—

Date	Number Tagged	Location
April 8th, 1953	1,010	Quilcene Bay, Hood Canal.
November 23rd to 25th, 1953	3,650	Mitchell Bay, San Juan Island.
March 18th, 1955	1,000	Agate Pass, Bainbridge Island.
April 19th and 20th, 1955	5,000	Holmes Harbour, Whidbey Island.
November 7th, 1955	153	Small Pox Bay, San Juan Island.
November 20th, 1955	4,000	Between Upright Head and Shag Rock, Orcas Island.
November 21st, 1955	4,000	North of Shoal Bay, Lopez Island.

Tagging of Juvenile Herring

Juvenile herring remain in inshore waters until early fall, when they migrate offshore in large schools and do not reappear in inshore waters again in appreciable numbers until they mature and join the spawning stocks two years later.

In order to provide information on the relationship between the juvenile herring stocks reared in certain areas and the spawning stocks that support the fisheries in these and other areas, a juvenile-herring tagging programme was initiated in 1952. Tagging

methods (Hourston, 1956) are similar to those used for adult herring, except that the tags are considerably smaller (13 by 3 by 0.5 mm. instead of 21 by 4 by 1 mm.).

Until 1954 this programme was centred on the stocks in the Barkley Sound (Area 23) region on the lower west coast of Vancouver Island. Tagging on a limited scale was also carried out in Areas 24 and 25 in the lower and upper west coast sub-districts respectively, and in Area 17A in the lower east coast sub-district. After 1954, tagging on the lower west coast of Vancouver Island was discontinued, and emphasis was shifted in 1955 to populations in the Strait of Georgia and the adjacent San Juan Islands region. Data on the 1955 juvenile taggings (Table II) are summarized below, along with comparable data for the 1951–53 taggings. No juveniles were tagged in 1954.

Year	District or Sub-district of Tagging						Total
	Upper West Coast	Lower West Coast	Middle East Coast	Lower East Coast	District 1	San Juan Islands (U.S.A.)	
1951	—	11,373	—	—	—	—	11,373
1952	1,940	25,993	—	—	—	—	27,933
1953	—	18,181	—	8,437	—	—	26,618
1955	—	—	7,291	5,650	3,149	3,553	20,055

TAG RECOVERY

As in previous seasons, tags were recovered in 1955–56 mainly from magnets in the reduction-plant meal-lines tended by plant crews. A small number of adult tags were recovered by a tag-detector operated by herring-investigation staff.

Tag-detector Operations

In the 1955–56 season, only one tag-detector was again operated, on an essentially experimental basis, in the Gulf of Georgia plant in Steveston. The modernization and increasing electrification of reduction plants has raised considerable practical problems to the continued successful operation of tag-detectors. In spite of technical improvements in the designs of the induction-type tag-detector to increase its inherent sensitivity and stability, detector efficiency again decreased. Detector efficiency was 36 per cent during the pre-Christmas period and 39 per cent during the post-Christmas period, as compared with 44 per cent during the pre-Christmas period in 1954–55, 51 per cent for the same period in 1953–54, and 80 per cent in 1951–52. The increased electrification of the reduction plants has resulted in an increase in possible sources, both of variations in line voltage and of switching transients. As was pointed out in the previous report in this series (Taylor, 1955), the amplitude of the pulse produced by a tag is little greater than that produced by such transients. Any improvements in detector sensitivity and amplification also result in an almost proportional increase in the reaction of the detector to these unwanted transients. Suitable screening of the detector may reduce or eliminate the effects of these transients, and experiments along this line are planned. On the other hand, the use of magnetic tags could be the answer to this problem. Such tags might produce a proportionately larger impulse on passing through the field of the tag-detector's magnet and hence produce sufficient increase in the signal-to-noise ratio. Magnetizing the tags could, however, reduce or eliminate the recovery by plant magnets of tags missed by the detector, as magnetic tags would tend to cling to the iron in the plant machinery whenever they came into contact with it. On the other hand, the press of the wet meal might prevent such contacts until the cooker or drier is reached, where the heat might be sufficiently great to destroy the magnetic properties of the tags. Thus an appreciable increase in the efficiency of detector recovery might be obtained by this means at the cost of a relatively small reduction in the efficiency of magnet recovery.

Operation of Magnets in Reduction Plants

Reduction plants differ in their efficiency in recovering tags from the catches processed. These differences arise from differences in the type of processing equipment used, in the location and effectiveness of the plant magnets, and in the diligence of plant crews in tending the magnets and submitting the tags found. To determine the efficiency of the various plants in recovering tags, tests were conducted in the same manner as in previous years (Stevenson, Hourston, Jackson, and Outram, 1952). A table of the average 1955–56 efficiency of each plant, along with its average efficiency for the previous season in parentheses, is given below:—

Plant	Adult Tags		Juvenile Tags	
	Number of Tests	Average Efficiency	Number of Tests	Average Efficiency
West Coast of Vancouver Island				
Port Albion	1 (1)	92 (90)	1 (1)	60 (30)
Steveston and Vicinity				
Imperial	3 (2)	84 (87)	3 (2)	53 (70)
Gulf of Georgia	3 (3)	94 (94)	3 (3)	80 (60)
Colonial	2 (2)	76 (91)	2 (2)	60 (85)
Phœnix	3 (4)	97 (98)	3 (3)	85 (93)
North Shore	2 (2)	89 (79)	2 (2)	75 (40)
Average	——	88 (90)	——	71 (68)
North and Central British Columbia				
Namu	2 (..)	91 (....)	2 (..)	65 (....)
Butedale	1 (2)	92 (83)	1 (..)	70 (....)
Port Edward	2 (2)	78 (87)	2 (..)	50 (....)
Seal Cove	2 (3)	79 (64)	2 (..)	35 (....)
Fairview	2 (..)	71 (....)	2 (..)	60 (....)
North Pacific	2 (..)	81 (....)	2 (..)	70 (....)
Average	——	82 (78)	——	58 (....)

In 1955–56, Port Albion was again the only plant operating on the west coast of Vancouver Island. The Namu reduction plant, enlarged in 1954, was modified prior to the 1955–56 season and magnets reinstalled. A new reduction plant in the Prince Rupert area, North Pacific, began operation in the 1955–56 season. Magnet tests were carried out for the first time at this plant and at the Fairview plant, which commenced operation in 1954–55 in the same locality.

In general, there was relatively little change in the efficiency of adult-tag recovery in 1955–56. North Shore, Butedale, and particularly Seal Cove showed increases in efficiency, while Port Edward and Colonial showed decreases. The drop in efficiency of Colonial may have resulted from the enlargement of the plant and installation of a cyclone-type drier.

The average efficiency of the major plants in Southern British Columbia in recovering the small juvenile-herring tags was only slightly greater in 1955–56 than in the previous season. However, individual plants showed considerable variation in efficiency between the two seasons. Port Albion, Gulf of Georgia, and North Shore showed marked increases in efficiency, while Imperial, Colonial, and, to a lesser extent, Phœnix showed marked decreases. Tests of efficiency in recovering juvenile tags were carried out in plants in Northern and Central British Columbia for the first time in 1955–56. The average efficiency was somewhat lower than for plants in Southern British Columbia. In general the plants appear to be about 80 per cent as efficient in recovering juvenile tags as in recovering adult tags. The ratio of juvenile to adult efficiency was 0.77 in 1955–56, 0.78 in 1954–55, and 0.83 in 1953–54.

Officers of the Federal Department of Fisheries carried out the magnet efficiency tests in plants in Northern and Central British Columbia, and personnel of the Biological Station, Nanaimo, B.C., those in other regions.

Recovery of Adult Tags by Plant Crews

A total of 2,666 tags, including thirty-five State of Washington tags, were recovered in 1955–56, approximately the same number as in the previous season. The distribution of adult-tag recoveries by area of tagging and probable sub-district of recovery is shown in Table III.

The varying amount of time taken for tags to pass through the plant machinery and reach the magnets in the meal-lines and the practice in most reduction plants of processing fish from several different areas in a relatively short period of time led to uncertainty as to the area of recovery of plant magnet returns. Only in cases where a plant processes fish from one area for a relatively long period of time can the area of recovery of tags found be considered certain. The same methods as employed in previous years (Tester and Stevenson, 1948) have been used to assign the most probable area of recovery to each plant magnet return. The most probable area of recovery could not be readily determined for 793 (29.7 per cent) of the tags (Table IV). Lack of precision in the determination of the exact area of recovery of plant magnet returns makes the analyses of movements within populations impossible and, as has been discussed in previous reports (Taylor and Outram, 1954, and preceding reports), limits the accuracy of the use of plant magnet returns in assessing the movement of fish between populations.

The analysis of movements between populations is based on estimates of the probable numbers of tags in the catches derived either from tag-detector recoveries or from plant magnet returns (Taylor and Outram, 1954). Because of the relatively small number of the former, obtained from one plant only in 1955–56, estimates of the probable numbers of tags in the catches derived from plant magnet returns were considered more accurate. Table IV shows by area of tagging and probable sub-district of recovery the probable numbers of tags in the catches that have been at liberty for one, two, three, and more than three years, along with the totals for each area and sub-district. Actual numbers of recoveries are shown in parentheses in all cases. As herring are tagged in March, and recoveries made in the winter fishery from November to early February or March, tagged fish are at liberty for up to four months less than the full period recorded.

The majority of recoveries from the middle and lower east coast of Vancouver Island populations were from the 1955 taggings of fish that had been at liberty for a year. (In 1955, tagging was confined to these two sub-districts.) In contrast to this, the majority of the recoveries from populations in Northern British Columbia and in the upper and lower west coast of Vancouver Island were from fish tagged in 1954 and 1953 that had been at liberty for two or more years. It will be noticed from Table IV that there is a tendency for the degree of dispersion from the sub-district of tagging to increase slightly the longer the tagged fish have been at liberty. This tendency is somewhat more marked in the Strait of Georgia populations than in those from Northern British Columbia. However, on the basis of the 1955–56 recoveries, this tendency does not seem sufficiently marked to warrant comparing the amount of dispersion from a population in different seasons on the strict basis of recoveries from fish at liberty for the same number of years. Such comparisons were therefore made, as in previous years, on the total probable number of tags recovered from each sub-district's tagging. A more important and more difficult source of error to estimate arises from differences in the degree of exploitation of the various populations in the same season and of the same population in different seasons. This effects comparisons between the same population in different seasons or different populations in the same season.

As in previous years, most of the recoveries were from the sub-district of tagging. In 1955–56 this " homing " tendency appeared to be strongest in the lower Queen Charlotte Islands and the middle east coast of Vancouver Island populations and weakest in the populations on the upper Queen Charlotte Islands and northern sub-district.

The number of recoveries of fish tagged on the lower and upper west coast of Vancouver Island was small in 1955–56, reflecting the lack of tagging there in 1955 and the light tagging in 1954. The indicated movement of herring from this region to other sub-districts was about 18 per cent (10/58). While this is somewhat less than the amount of emigration in the previous year (24 per cent), it is probably still above average for recent years. Additional recoveries were made from lower Queen Charlotte Islands, the lower central, and the middle and lower east coast of Vancouver Island sub-districts.

Movement of lower east coast herring was greatest to the middle east coast sub-district, where 13 per cent (77/586) of the recoveries were made. This compares with 20 per cent in 1954–55 and 16 per cent in 1953–54. Movements to the lower central sub-district and west coast of Vancouver Island amounted to about 1 per cent each (6/586 and 8/586 respectively). More lower east coast tags were recovered from the lower west coast sub-district (seven tags) than from the upper west coast sub-district (one tag). Considering the small number of recoveries involved and the great difference in the size of the catch in the two west coast regions, this may not represent an actual difference in movement to the two areas.

A total of thirty-five recoveries were made from tags inserted in the San Juan Islands and Puget Sound region by State of Washington Department of Fisheries. Of these tags, one was recovered from the lower central sub-district, one from the lower west coast sub-district, and the remainder from the lower east coast sub-district. Of the lower east coast recoveries, twenty-two were from herring tagged in the San Juan Islands region immediately prior to or during the lower east coast fishery, ten were from fish tagged in Holmes Harbour, Whidbey Island, in mid-April, 1955, and one from fish tagged at Agate Pass in Puget Sound in March, 1955. The large number of recoveries from the San Juan Islands region is to be expected. This locality is within 20 miles of the main centre of the lower east coast fishery, and the San Juan Islands herring are probably an adjunct to the main migrating lower east coast population. The Holmes Harbour and Agate Pass fish may represent local stocks which intermix to a more limited extent with the lower east coast fish.

Movement from the middle east coast population amounted to 6 per cent (40/647) in 1955–56. This is approximately the same as in 1954–55 (4 per cent, 6/152), but considerably less than the average of 45 per cent for the years 1936 to 1952 (Stevenson, 1955). Approximately 5 per cent of the middle east coast tags were recovered from the lower east coast sub-district, compared to 2 per cent in 1954–55, 17 per cent in 1953–54, and 6.8 per cent from magnet recoveries, or 29.9 per cent from detector recoveries in 1951–52. Although, as in 1954–55, the movement of fish tagged in Area 17A to the middle east coast (23 per cent) was greater than for those tagged in Area 17B (7 per cent) or Area 18 (6 per cent), the movement from Areas 17A and 17B in 1955–56 was somewhat less than the previous year (Area 17A, 46 per cent, and Area 17B, 14 per cent). The movement of middle east coast fish to the lower east coast sub-district was greater from Area 14 (14 per cent) than from Area 15 (4 per cent) or Area 13 (< 1 per cent). Mixing between stocks in the middle and lower east coast sub-districts is thus greatest between the contiguous areas — northernmost lower east coast area and southernmost middle east coast area. This pattern of recoveries, shown by fish tagged in the middle and lower east coast sub-districts, thus tends to confirm the hypothesis that herring enter the Strait of Georgia from two directions — from the south into the lower east coast sub-district and from the north into the middle east coast sub-district.

Emigration from the lower central sub-district amounted to 16 per cent (76/472) in 1955–56, the main portion of which (9 per cent) was to the lower Queen Charlotte Islands. Limited movement of lower central fish to the upper Queen Charlotte Islands, northern, and middle and lower east coast of Vancouver Island sub-districts was also indicated.

The 1955–56 fishery in the upper central sub-district was too small (less than 2,000 tons) to provide tags certain as to area of recovery or to be able to assign recoveries to it

with any degree of certainty. About 85 per cent (194/229) of the recoveries of fish tagged in the upper central sub-district were from the upper or lower central sub-districts, 5 per cent were from the northern sub-district, 6 per cent from the lower Queen Charlotte Islands sub-district, and 2 per cent each from the upper Queen Charlotte Islands and the middle east coast sub-districts.

Of the recoveries of fish tagged in the northern sub-district, 55 per cent (143/260) were from the lower Queen Charlotte Islands sub-district and 12 per cent (31/260) from the lower central sub-district, as compared to 31 per cent (81/260) from the sub-district of tagging. This pattern of recoveries is quite different from that shown by northern fish in previous years. In 1954–55 and in 1953–54, emigration amounted to only 4 per cent (Taylor, 1955). On the basis of recoveries of fish tagged and recovered between 1936 and 1952, Stevenson (1955) found that the average emigration from the northern sub-district amounted to 23 per cent. The extent to which the greater emigration from the northern population represents an actual change in migration pattern is uncertain because:—

(1) The small northern fishery occurred concurrently with the large lower Queen Charlotte Islands and lower central fisheries. This made it difficult to decide with a reasonable degree of certainty which tags were actually recovered from the northern sub-district.

(2) The possibility exists that the herring in Tuck Inlet and Morse Basin, where the 1955–56 fishery was centred, represent a local population, not part of the main population usually fished around Porcher Island. Results in other years indicate that it was this latter population that had been tagged. A local population would probably not contain as great a proportion of tagged fish as the main population, and hence the number of recoveries from it would be expected to be proportionately low. It is interesting to note that during the season there were reports of a large body of herring off Porcher Island that remained out of reach of the fishery. This body of herring might have been at least part of the normal main migratory population which for some reason did not become available to the fishery in 1955–56. This speculation receives some support from the amount of spawn deposited in this sub-district in 1956. Spawning was only slightly less (12 per cent) than in 1955. The decrease is not as great as might have been expected in view of the very poor 1955–56 catch. Spawning was not below the average for recent years. It increased in Areas 3 and 4; the decrease occurred in Area 5, where a large spawning in Wilson Inlet, recorded in 1955, for the first time in recent years was not repeated.

The fishery in 1955–56 in the lower Queen Charlotte Islands sub-district far exceeded in size that in the upper Queen Charlotte Islands sub-district. This is in contrast to the previous two seasons, in which the upper Queen Charlotte Islands fishery had far exceeded in size that in the lower Queen Charlotte Islands. The bulk of recoveries of fish tagged in the lower Queen Charlotte Islands were from that area. Emigration amounted to only about 3 per cent (19/619), divided almost equally to the upper Queen Charlotte Islands, northern, and lower central sub-districts. On the other hand, of fish tagged in the upper Queen Charlotte Islands, 64 per cent (85/132) were recovered from the area of tagging, compared to about 96 per cent in 1954–55. Movement to the lower Queen Charlotte Islands sub-district amount to 20 per cent (27/132); to the northern sub-district, 8 per cent (11/132); and to the lower central sub-district, 5 per cent (6/132). Three recoveries were made from Southern British Columbia populations. The greater amount of emigration indicated in 1955–56 may be, in part, due to greater errors in the correct assignment of tags to area of recovery. The upper Queen Charlotte Islands fishery, like the northern fishery, occurred concurrently with

the large lower Queen Charlotte Islands and lower central fisheries, and a proportion of the tags actually recovered in the upper Queen Charlotte Islands may have been assigned in error to the lower Queen Charlotte Islands.

Recovery of Juvenile Tags by Plant Crews

Plant crews recovered twenty-two juvenile-herring tags during the 1955–56 fishing season. Only eight of these could be assigned with certainty to catches from a specific area but probable recovery areas for seven more were determined on the same basis as that employed in analysing adult-tag returns. The twenty-two returns obtained during the 1954–55 fishery and the six from the 1953–54 fishery were similarly analysed, and the resulting probable returns were corrected for magnet efficiency and the proportion of the catch searched by magnets (Hourston, 1956). The results were tabulated by sub-district (Table V), as the number of returns was too small to make analysis by area worth while. Methods employed, and consequently difficulties encountered and assumptions made, were similar to those in the analysis of adult-tag returns.

Fish tagged as juveniles showed 56 per cent homing after two years and 62 per cent after three years. This is considerably less than that shown by fish tagged as adults in the same sub-district (90 and 74 per cent respectively). Data were considered inadequate for comparison of tags at large for one year, as only three such juvenile tags were recovered. Thus the juveniles show greater wandering tendencies than do adults. A larger unit of population than the adult population may therefore be necessary for considerations relating population data on juveniles to that on adults. Most of the juveniles emigrating from the lower west coast sub-district moved to the lower east coast sub-district, and these two sub-districts may form a suitable unit for such considerations. However, it remains to be seen whether juveniles tagged on the lower east coast reciprocate this emigration. If so, it would appear that the depletion of one adult population would be compensated in part by immigration of new recruits from one or more of the others, provided, of course, they were not depleted at the same time.

AGE COMPOSITION

The age composition of the herring stocks fished was estimated from age determinations for each of 100 fish in 288 samples removed from herring packers in the approximate proportion of one sample per 900 tons of fish caught (Isaacson, MS.). Practical difficulties precluded close adherence to this ratio, resulting in a variation of 105 to 3,722 tons per sample.

When the stocks in two sections of the Queen Charlotte Islands showed appreciable differences in age composition, the presence of two separate populations was suggested. The returns of tagged fish and the data on average length and weight supported this hypothesis. Thus Area 2A (E) is occupied by the upper Queen Charlotte Islands population and Area 2B (E) by the lower Queen Charlotte Islands population. For the sake of consistency, the north central (Area 6) and south central (Areas 7, 8, 9, and 10) populations have been redesignated upper and lower central, and the north-west coast of Vancouver Island (Areas 25, 26, and 27) and the south-west coast of Vancouver Island (Areas 21, 23, and 24) populations have been renamed upper and lower west coast of Vancouver Island. Sub-districts have been modified accordingly (Fig. 1).

For the third successive year, the 1951 year-class formed a major portion of the fishing stocks, dominating the lower Queen Charlotte Islands, lower central, and upper east coast and middle east coast of Vancouver Island populations. It shared dominance with the 1953 year-class in the upper Queen Charlotte Islands population and, to a lesser extent, in the northern population. The 1953 year-class dominated the lower east coast and lower west coast populations. The 1954 year-class formed the vast majority of the

upper central population, and appears to be at least as strong in most other populations as the 1953 year-class was as II-year fish. It would thus appear that, over the coast as a whole, both the 1953 and 1954 year-classes are above the average abundance of the last seven years, but not as large as the big 1951 year-class. The 1952 year-class was the poorest of the seven, followed by the 1949, 1948, and 1950 year-classes in that order. Thus the over-all population level of the fishing stocks will probably be lower in 1956–57 than in 1955–56. However, the recruitment of the above-average 1954 year-class should compensate somewhat for the decline in the contribution of the strong 1951 year-class.

The consistency with which the newly recruited year-class has each year dominated the heavily exploited lower east coast and lower west coast populations and the relative stability of the extent of this domination suggests that recent fluctuations in year-class strength have not been major, in these sub-districts at least. The ability of the 1951 year-class to dominate catches over a three-year period in more northerly sub-districts suggests more violent fluctuations in year-class strength in these sub-districts or that the fishery does not catch as large a proportion of a strong year-class as it enters the fishery. The latter alternative could result from relatively large portions of the year-class not being recruited until age V or age VI.

The actual contribution of these year-classes to the fishery in each population in terms of numbers of fish may be determined from the age composition, average weight at each age, and total catch. These calculations were made for each area and summed by sub-district (Table VII). The table shows the great strength of the 1951 year-class even more strikingly than the age-composition data. It experienced the strongest recruitment of any of the five most recent year-classes in the lower each coast and lower west coast sub-districts, a fact not evident from the age composition alone.

AVERAGE LENGTH AND WEIGHT

With the exception of the upper Queen Charlotte Islands, upper central, and upper east coast populations, the average length (Table VIII) and weight (Table IX) of fish from each year-class showed little variation from population to population (Isaacson, MS.). Relatively large differences in the very old and very young fish may be attributed to the small number of fish sampled in these age-groups.

For the past three fishing seasons, the upper east coast fish of all ages have been smaller, both in length and weight, than the fish in other sub-districts, whereas in 1952–53 they were larger. This supports the hypothesis that the upper east coast population is made up largely of local stocks subject to different environmental effects than the migratory populations. The upper Queen Charlotte Islands fish and the upper central fish were smaller at Ages III and IV than in other sub-districts, suggesting that these fish also are subjected to different environmental stresses than the other populations up to at least Age IV. This gives additional support to their classification as separate populations, as proposed from the age-composition analysis.

No appreciable change in the average length and weight of the various age-groups in 1955–56 is evident, except in the upper east coast where the fish were smaller than in the previous year. The lower east coast and northern fish tended to be slightly shorter than in the previous year, but this difference was not reflected in the average weights. The upper and lower central populations appear to have been a year behind in their growth from the third year on, as in 1953–54 and 1954–55. This trend is continued in 1955–56 in the upper central population. This could have occurred as a result of inclusion of a false annulus on the scales when ageing the fish, although a spot check on these scales failed to show any such possibility. A more thorough check will be made before any final decision is reached in this matter. In any event it would appear that these two populations resemble each other more closely than do any other two populations.

SEX RATIO

The sex ratio (the number of females divided by the number of males) has fluctuated between 0.96 and 1.11 over the past five years (Table X). In 1955–56 it was 1.09, slightly higher than the average for the past five years (1.05). Although, as a general rule, females tend to predominate in the older age-groups, the sex ratio bears no apparent relationship to the average age of fish in the catch or to population size as indicated by the size of the catch. Males were proportionally more abundant in samples from the lower east coast, whereas females tended to predominate elsewhere.

EXTENT AND INTENSITY OF SPAWNING

In addition to providing the initial size of the new year-class, estimates of the extent and intensity of spawn depositions give an index of the relative size of the spawning escapement. These estimates are made each spring by officers of the Federal Department of Fisheries for the entire British Columbia coast. Independent and more detailed surveys of the lower and middle east coast of Vancouver Island sub-districts were also conducted in 1955 and 1956 by staff members of the Biological Station, Nanaimo, B.C. The size of the spawning population is determined from the amount of eggs deposited, sex ratio, and fecundity of the different age-groups. The resulting calculation is taken to represent escapement from the fishery, since natural mortality during the short period between the closure of the fishery and the commencement of spawning is considered to be negligible.

The length of each spawning-ground was measured by either pacing along the beach or by reference to large-scale charts. When the width was found to be extremely small or large (that is, less than 5 yards or greater than 100 yards), the actual length was converted to an equivalent length based on a standard width of 30 yards. The intensity of spawning was estimated as one of five categories—very light, light, medium, heavy, or very heavy—depending on the number of eggs deposited per unit area of vegetation. These data were converted to the number of statutory miles of spawn at a standard intensity of medium in each statistical area (Table XI).

A summary of the results of the 1956 surveys (Outram, 1956) is presented here. The total amount of herring spawn deposited was 188.1 miles, a reduction of 13 per cent from the 1955 level. The 1956 spawning depositions were slightly below the average of the last ten years. Increases in spawn depositions over the previous year occurred in the upper east coast (73 per cent), upper west coast (200 per cent), and lower west coast (41 per cent) of Vancouver Island sub-districts. Marked decreases in the amount of spawn deposited were recorded in the upper central (96 per cent), lower central (38 per cent), lower east coast of Vancouver Island (51 per cent), and middle east coast of Vancouver Island (31 per cent) sub-districts. Smaller decreases in spawn deposition occurred in the lower Queen Charlotte Islands (14 per cent) and northern (12 per cent) sub-districts. Of the numerous reductions in spawn deposition that occurred throughout British Columbia, only the sharp decrease in the upper central sub-district appears to be of a serious nature. On the other hand, the amount of spawn deposited in the upper west coast of Vancouver Island sub-district was nearly the largest on record.

In spite of the abundance of fish in the Queen Charlotte Islands region during the fishing season, the amount of spawn recorded in the lower Queen Charlotte Islands was slightly lower than the previous year. In the upper Queen Charlotte Islands, spawning was virtually non-existent for the second successive year.

The small reduction in spawn deposition in the northern sub-district was due to the failure of the large 1955 spawning in Wilson Inlet (Area 5) to reoccur. The reduced spawning in Area 5 was partly compensated for by slight increases in Areas 3 and 4.

The amount of spawn deposited in the upper and lower central sub-districts continued to decline in 1956. A small increase in spawn deposition in Area 10 was more than offset by sharp reductions in Areas 6, 7, 8, and 9. The absence of spawnings in the usually productive Myers Pass region (Area 6) was responsible for the large decrease in spawn deposition in the upper central sub-district.

In the upper east coast of Vancouver Island sub-district, unusually large spawnings in Knight Inlet and Mackenzie Sound (Area 12) maintained spawning at an average level for the sub-district.

On the middle east coast of Vancouver Island there was less spawning in all regions, except Area 14, where a large spawning in Comox Harbour kept the spawn deposition for the sub-district at the average level. Spawnings failed to occur in Area 15 this year for the first time; spawning in this area during the past ten years has averaged about 3.4 miles.

Although there was a marked reduction in the amount of spawning on the lower east coast of Vancouver Island for the third successive year, the 1956 level remained about equal to the average of the last ten years. The lack of extensive spawnings along the shore-line on either side of Stuart Channel (Area 17B) was mainly responsible for the decreases in this sub-district. Reductions in the size of the Area 17B spawnings were partly compensated for by increases in Area 18, particularly in Saanich Inlet.

The increase in the amount of spawn deposited in the lower west coast sub-district results from greater spawning in Area 23, which more than compensated for the sharp reduction in Area 24.

The increase in the amount of spawn deposited in the upper west coast of Vancouver Island sub-district resulted primarily from a large spawning at Nuchatlitz Village (Area 25), which was responsible for about four-fifths of the total amount of spawn found in this sub-district.

On the coast as a whole, the amount of spawn deposited has been decreasing continuously for the past four years. The continuous increase in the two west coast populations has failed to compensate for decreases in Areas 6, 15, and 17B. However, the 1953 to 1955 spawnings were above average in extent, and the 1956 spawning is about average for the ten-year period immediately preceding the record spawning of 1953.

DISCUSSION

The status of the major herring populations in British Columbia may now be discussed in the light of the information presented above.

On the basis of tag returns and data on year-class strength and average length and weight of fish at each age, two populations were found in each of what were formerly known as the Queen Charlotte Islands, central, and west coast sub-districts. The latter two sub-districts were treated in two parts in the 1954–55 report (Taylor, 1955), and indications of more than one population in each have been noted for some time. Previously these divisions were known as north and south, but, for the sake of consistency and to avoid confusion, they have been redesignated upper and lower. The 1955–56 fishery in the Queen Charlotte Islands was the first in recent years to appreciably exploit both Areas 2A (E) and 2B (E), and thus it was not until this year that the presence of two populations was clearly indicated.

The populations in the lower Queen Charlotte Islands and middle east coast of Vancouver Island sub-districts showed the strongest homing tendencies, as was the case in 1954–55. However, the upper Queen Charlotte Islands and northern populations, which also showed strong homing tendencies in 1954–55, were the poorest in this respect in 1955–56. This greater wandering in 1955–56 was reflected in the catches, which were lower than anticipated that season. Emigration from the lower west coast sub-district was again relatively high in 1955–56, but was lower than in

the previous season. The increased catch in this sub-district may reflect the greater homing tendency in 1955–56.

In 1955–56, herring in British Columbia were generally more abundant than in the previous year and than the average for the past five years. The total catch was one-third greater than in 1954–55 and one-fourth greater than the five-year average, while the amount of spawn deposition decreased only slightly from the previous year and remained equal to the average of recent years. The record size of the 1955–56 catch may be attributed to large increases in abundance in the lower Queen Charlotte Islands and lower central sub-districts. With the exception of the catch on the middle east coast of Vancouver Island, which was slightly above average, and that on the lower west coast of Vancouver Island, which was average, catches in the other sub-districts were below average.

The amount of spawn deposited increased considerably in the lower and upper west coast and upper east coast sub-districts but decreased elsewhere.

In the upper Queen Charlotte Islands sub-district there was a marked reduction in catch, and no spawning was located for the second consecutive year. The decrease in abundance may be partially attributed to the decline in numbers with age of the strong 1951 year-class which was not compensated by recruitment from the weak 1952 year-class. However, it would appear that this population did not become as available to the fishery in 1955–56 as in the previous year, and this may be the major cause of the decrease in catch. In 1956–57, abundance will probably be even lower, but until this population can be related to its spawning-grounds, it will be impossible to assess its availability and predict its future strength with any confidence.

The lower Queen Charlotte Islands catch showed a tremendous increase over 1954–55, possibly also resulting from a difference in availability to the fishery. The 1951 year-class made up the major portion of the catch. The amount of spawn deposited showed a slight decrease in 1956, but not nearly enough for the decrease in escapement to account for the increase in catch. As the 1951 year-class cannot be expected to make a major contribution as VI-year fish next year, the 1956–57 population will probably be appreciably smaller, but should still be about average.

There was a sharp decline in catch in the northern sub-district, accompanied by a slight decrease in escapement, as indicated by the amount of spawn deposited. The decrease in abundance may be traced to the exceedingly poor contribution of the 1952 year-class as IV-year fish, the age-group which usually dominates this population. But for the excellent contribution of the 1953 year-class, this population would have been exceedingly small in 1955–56. Abundance should be greater in 1955–56, but not above average.

In the upper central sub-district, one of the biggest decreases in recent years was experienced in 1955–56 in both catch and spawn deposition. The good 1951 year-class was too old to make an appreciable contribution to the stock, and both the 1952 and 1953 year-classes were exceedingly poor in this population. Consequently only an unusually good contribution of the 1954 year-class as II-year fish sustained the population at a level high enough to permit a fishery. Had this year-class been equally poor as its immediate predecessors, the population might not have been large enough to provide adequate spawning. This population should be appreciably larger in 1955–56, but probably not above average.

In the lower central sub-district, spawning was down about one-third from the level of the past three years, but the catch was nearly double the average for that time. The sustained abundance of the very strong 1951 year-class as V-year fish in this sub-district, along with nearly average contributions by the 1952 and 1953 year-classes and a good recruitment of the 1954 year-class as II-year fish, resulted in a very high level of abundance. Abundance should be about average next year.

The upper east coast catch declined considerably in 1955–56, but since spawn deposition showed a marked increase, the general level of abundance was probably about the same as in the previous year. However, since the strong 1951 year-class, which dominated the catch as V-year fish this year, cannot be expected to make a major contribution to next year's population, abundance will probably decline in 1956–57.

In the middle east coast sub-district, the 1955–56 catch was slightly above average, but the extent of spawn deposition was slightly below average. The relatively weak contribution of the 1953 year-class as III-year fish was offset by the above-average contributions of the 1951 and 1952 year-classes. The 1954 year-class may be sufficiently strong to sustain the present level of abundance in 1956–57 in spite of the weakness of the 1953 year-class, but it is more likely that abundance will decrease slightly.

The catch on the lower east coast was average in size, but, for the third successive year, the extent of spawn deposited showed a sharp decline (approximately one-half that of 1955, one-third that of 1954, and one-fifth that of 1953). Since the 1954 year-class appears to be at least average in strength, the decline in spawning in 1954 was not sufficient to affect the strength of the resulting year-class. According to reports from fishermen and local residents, the juvenile herring were more abundant than usual in 1955, and surveys by Biological Station personnel of the juvenile herring in this sub-district indicate the 1955 and 1956 year-class are comparable in strength. Thus the amount of spawn deposited those years was also probably adequate. Unless the intensive fishery in the lower east coast can continue to reduce the spawning stock (quota extensions have not been fully taken during the past two seasons), there appears to be no real danger of the population not sustaining itself. No appreciable change in abundance is anticipated in 1956–57.

After a poor showing in 1954–55, both catch and spawn in the lower west coast sub-district increased in 1955–56 to the average level for the past five years. The newly recruited 1953 year-class was of average strength, whereas the 1952 year-class failed to provide the usual number of new recruits in the 1954–55 fishery. As the 1954 year-class appears to be at least as strong as that of 1953, the population level in 1956–57 should be slightly higher than in 1955–56.

In the upper west coast sub-district, no appreciable fishery materialized in 1955–56 and no samples were obtained. However, the extent of spawning was three times that of the previous year and was more than double the average for the past four years. Consequently abundance in this sub-district was probably sustained at least at the average level in 1955–56. The lateness of the inshore movement of the fish did not make them available to the fishery.

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SUMMARY

Analysis of recent data as to the status of the major herring stocks has indicated the presence of ten major populations. The Queen Charlotte Islands, central, and west coast sub-districts have been divided into lower and upper populations on the basis of differences in their age composition and average size, and from the extent of mixing indicated by the returns of tagged fish.

Emigration, as indicated by the returns of tagged fish, was greatest from the upper Queen Charlotte Islands (36 per cent) and northern (67 per cent) populations, both of which showed strong homing tendencies in 1954–55. This greater wandering was reflected in reduced catches from these sub-districts in 1955–56. Most of the emigration

was to neighbouring populations. Homing was greatest to the lower Queen Charlotte Islands (97 per cent) and middle east coast of Vancouver Island (94 per cent) sub-districts, whose populations also showed little emigration in 1954–55.

Returns of tags inserted in juvenile herring on the lower west coast of Vancouver Island indicate that mixing between that stage and recruitment is greater than that shown by fish tagged as adults and at large for a comparable period. Thus depletion in any one population should be buffered by the excess in immigration over emigration prior to recruitment.

A record catch of 250,441 tons was taken during the 1955–56 fishing season. Large increases in abundance in the lower Queen Charlotte Islands and lower central sub-districts were mainly responsible for the increase in catch. These two populations were sustained mainly by the strong 1951 year-class as V-year fish.

The total amount of spawn deposited was slightly less in 1956 than in 1955, with appreciable increases in the upper east coast and upper and lower west coasts of Vancouver Island sub-districts nearly offsetting decreases in all other sub-districts. Spawn deposition in 1956 was average for recent years. The extent of spawn deposition on the lower east coast of Vancouver Island has declined steadily since 1953 (from 102.5 miles in 1953 to 21 miles in 1956) with the increase in exploitation by the fishery. However, surveys of the juvenile (I-year) stocks in 1955 and 1956 and the contributions of the previous two year-classes to the fishery fail to show any corresponding decrease in the size of the resulting brood.

Fish were relatively more abundant in 1956 than in 1955 in the lower Queen Charlotte Islands, lower central, and lower west coast of Vancouver Island sub-districts, and less abundant in the upper Queen Charlotte Islands, northern, upper central, lower east coast of Vancouver Island, and upper west coast of Vancouver Island sub-districts. The strong 1951 year-class continued to form the major portion of most of the populations in the north, while the above-average 1953 year-class dominated in the south. The 1952 year-class was relatively small in most populations. Although the 1954 year-class appears to be above average, it is not likely to sustain the present level of abundance in 1956–57, as the 1951 year-class will cease to contribute appreciably to the population.

No appreciable difference in the size of fish of each age was noted in 1955–56. Fish from the upper east coast at ages II, III, and IV were again smaller than those in neighbouring populations. This trend probably indicates different growth conditions for this population, supporting the hypothesis that it is made up mainly of local stocks. The general trend of a decrease in size at all ages with an increase in latitude continued in 1955–56. Females continued to slightly outnumber males (except on the lower east coast) for the fifth straight year.

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* Reprints were published in year following the date of publication of report.

Table I.—Tags Inserted in Adult Herring during the 1956 Spawning Season

Code Letters	Tagging Code	Place	Date	Number
		Area 13		
NIN	20A	Carrington Bay	Apr. 10	508
NKN	20A	Carrington Bay	Apr. 10	507
NLN	20A	Carrington Bay	Apr. 10	514
		Area 14		
LOL	20B	French Creek	Mar. 8	231
LNL	20B	French Creek	Mar. 8	205
LPL	20B	French Creek	Mar. 8	297
JZJ	20C	Cape Lazo	Mar. 9	485
JXJ	20C	Cape Lazo	Mar. 9	483
JYJ	20C	Cape Lazo	Mar. 9	471
IJI	20D	N.W. Hornby	Mar. 11	504
IKI	20D	N.W. Hornby	Mar. 11	523
ILI	20D	N.W. Hornby	Mar. 11	505
JLJ	20E	Thames Creek	Mar. 18	510
JMJ	20E	Thames Creek	Mar. 18	500
JNJ	20E	Thames Creek	Mar. 18	507
JTJ	20F	Northwest Bay	Mar. 19	498
JUJ	20F	Northwest Bay	Mar. 19	495
JWJ	20F	Northwest Bay	Mar. 19	499
		Area 16		
NAN	20G	Porpoise Bay	Mar. 15	508
NBN	20G	Porpoise Bay	Mar. 15	507
NCN	20G	Porpoise Bay	Mar. 15	503
		Area 17A		
IEI	20H	Departure Bay	Feb. 8	503
III	20H	Departure Bay	Feb. 8	507
IHI	20H	Departure Bay	Feb. 8	239
		Area 17B		
IPI	20J	Coffin Point	Mar. 12	480
ISI	20J	Coffin Point	Mar. 12	492
ITI	20J	Coffin Point	Mar. 12	517
KSK	20K	Preedy Harbour	Mar. 30	507
KTK	20K	Preedy Harbour	Mar. 30	509
KYK	20K	Preedy Harbour	Mar. 30	503
		Area 18		
LDL	20L	Finlayson Arm	Apr. 6	506
LJL	20L	Finlayson Arm	Apr. 6	508
LKL	20L	Finlayson Arm	Apr. 6	504
		Total		15,535

Table II.—Tags Inserted in Juvenile Herring during the Summer of 1955

Code Letters	Tagging Code	Place	Date	Number
		MIDDLE EAST COAST OF VANCOUVER ISLAND		
		Area 14		
GAAG	19N	Off Union Bay, Baynes Sound	Sept. 22	482
GBBG	19N	Off Union Bay, Baynes Sound	Sept. 22	480
GCCG	19N	Off Union Bay, Baynes Sound	Sept. 22	547
GDDG	19N	Off Union Bay, Baynes Sound	Sept. 22	510
GEEG	19N	Off Union Bay, Baynes Sound	Sept. 22	492
GGGG	19N	Off Union Bay, Baynes Sound	Sept. 22	524
		Area 16		
GHHG	19O	St. Vincent Bay, Jervis Inlet	Sept. 25	519
GIIG	19O	St. Vincent Bay, Jervis Inlet	Sept. 25	529
GJJG	19O	St. Vincent Bay, Jervis Inlet	Sept. 25	526
GKKG	19O	St. Vincent Bay, Jervis Inlet	Sept. 25	552
GLLG	19O	St. Vincent Bay, Jervis Inlet	Sept. 25	547
GMMG	19O	St. Vincent Bay, Jervis Inlet	Sept. 25	521
GNNG	19O	St. Vincent Bay, Jervis Inlet	Sept. 25	524
GOOG	19O	St. Vincent Bay, Jervis Inlet	Sept. 25	538
		LOWER EAST COAST OF VANCOUVER ISLAND		
		Area 17B		
DXXD	19P	Off Grappler Rock, Kuper Island	Sept. 14	506
DYYD	19P	Off Grappler Rock, Kuper Island	Sept. 14	520
EDDE	19P	Off Grappler Rock, Kuper Island	Sept. 14	525
EXXE	19P	Off Grappler Rock, Kuper Island	Sept. 14	524
EYYE	19P	Off Grappler Rock, Kuper Island	Sept. 14	514
EZZE	19P	Off Grappler Rock, Kuper Island	Sept. 14	541
GYYG	19Q	Ruxton Passage, De Courcy Island	Sept. 26	412
		Area 18		
GXXG	19R	Village Bay, Mayne Island	Sept. 30	516
HIIH	19R	Village Bay, Mayne Island	Sept. 30	517
HTTH	19R	Village Bay, Mayne Island	Oct. 1	532
HWWH	19R	Village Bay, Mayne Island	Oct. 1	553
		DISTRICT NO. 1		
		Area 28		
GPPG	19S	Gambier Island, Howe Sound	Sept. 25	518
GRRG	19S	Gambier Island, Howe Sound	Sept. 25	519
GSSG	19S	Gambier Island, Howe Sound	Sept. 25	519
GTTG	19S	Gambier Island, Howe Sound	Sept. 25	519
GUUG	19S	Gambier Island, Howe Sound	Sept. 25	530
GWWG	19S	Gambier Island, Howe Sound	Sept. 25	544
		SAN JUAN ISLANDS		
HUUH	19T	Reid Harbour, Stuart Island	Oct. 3	498
HXXH	19T	Reid Harbour, Stuart Island	Oct. 3	536
IAAI	19T	Reid Harbour, Stuart Island	Oct. 3	476
IBBI	19T	Reid Harbour, Stuart Island	Oct. 3	496
ICCI	19T	Reid Harbour, Stuart Island	Oct. 3	472
IDDI	19T	Reid Harbour, Stuart Island	Oct. 3	503
IEEI	19T	Reid Harbour, Stuart Island	Oct. 3	486
IFFI	19T	Reid Harbour, Stuart Island	Oct. 3	486
		Total		20,053

Table III.—Number of Tags Recovered by Plant Crews, according to Area of Tagging and Probable Sub-district of Recovery, for the 1955–56 Fishing Season

Sub-district and Area of Tagging	Tagging Code	Year of Tagging	Probable Sub-district of Recovery									Total
			Upper Queen Charlotte Islands	Lower Queen Charlotte Islands	Northern	Upper and Lower Central[1]	Middle East Coast	Lower East Coast	Lower West Coast	Upper West Coast	?	
Upper Queen Charlotte Islands												
Area 2A (E)	18T	1954	5	8	—	1	1	1	—	—	19	35
	18U	1954	8	6	1	3	1	—	—	—	29	48
	18W	1954	5	2	—	1	—	—	—	—	15	23
Lower Queen Charlotte Islands												
Area 2B (E)	16CC	1952	—	64	—	2	—	—	—	—	18	84
	17QQ	1953	—	93	—	—	—	—	—	—	27	120
	17RR	1953	—	63	—	—	—	—	—	—	14	77
	18S	1954	—	270	—	2	—	—	—	—	80	352
Northern												
Area 4	15T	1951	—	1	—	—	—	—	—	—	2	3
	16Z	1952	—	2	—	—	—	—	—	—	2	4
	16AA	1952	—	2	1	1	—	—	—	—	1	5
	16BB	1952	—	—	—	—	—	—	—	—	1	1
	17MM	1953	—	7	2	3	—	—	—	—	11	23
	17NN	1953	—	6	—	—	—	—	—	—	3	9
	17PP	1953	—	8	—	1	—	—	—	—	5	14
	18P	1954	—	5	1	—	—	—	—	—	3	9
	18Q	1954	—	11	—	2	—	—	—	—	15	28
	18R	1954	—	20	2	5	—	—	—	—	19	46
Area 5	14CC	1950	—	2	—	—	—	—	—	—	—	2
	18N	1954	—	27	—	7	—	1	—	—	24	59
Upper Central												
Area 6	15V	1951	—	1	—	—	—	—	—	—	2	3
	15W	1951	—	—	—	1	—	—	—	—	—	1
	17LL	1953	—	1	—	18	1	—	—	—	11	31
	18M	1954	1	3	1	108	1	—	—	—	46	160
Lower Central												
Area 7	14HH	1950	—	—	—	—	—	—	—	—	1	1
	15X	1951	—	—	—	2	—	—	—	—	—	2
	15AA	1951	—	—	—	3	—	—	—	—	1	4
	15BB	1951	—	—	—	1	—	—	—	—	2	3
	16U	1952	—	—	—	3	—	—	—	—	—	3
	16W	1952	—	—	—	8	1	—	—	—	3	12
	16X	1952	—	1	—	10	1	—	—	—	5	17
	16Y	1952	1	1	—	10	1	—	—	—	9	22
	17EE	1953	—	1	—	24	—	1	—	—	4	30
	17FF	1953	—	4	—	26	—	2	—	—	10	42
	17GG	1953	—	3	—	17	—	—	—	—	7	27
	17HH	1953	—	1	—	11	—	—	—	—	2	14
	17II	1953	—	2	—	8	—	—	—	—	2	12
	17JJ	1953	—	—	—	2	1	—	—	—	—	3
	17KK	1953	—	3	1	19	—	—	—	—	6	29
	18K	1954	—	5	1	44	—	—	—	—	19	69
	18L	1954	—	4	—	84	2	1	—	—	32	123
Area 10	14EE	1950	—	—	—	—	—	—	—	—	1	1
	15CC	1951	—	—	—	1	1	—	—	—	—	2
Upper East Coast												
Area 12	17DD	1953	—	—	—	1	1	—	—	—	—	2
Middle East Coast												
Area 13	19A	1955	—	—	—	—	116	1	—	—	29	146

[1] It was impossible to separate returns from the upper and lower central sub-districts as catches from these regions were mixed freely in reduction plants. However, since the catch from the upper central sub-district was quite small in comparison with that from the lower central, it is assumed that most, if not all, of these recoveries were taken in the lower central sub-district.

Table III.—Number of Tags Recovered by Plant Crews, according to Area of Tagging and Probable Sub-district of Recovery, for the 1955–56 Fishing Season—Continued

Sub-district and Area of Tagging	Tagging Code	Year of Tagging	Probable Sub-district of Recovery									Total
			Upper Queen Charlotte Islands	Lower Queen Charlotte Islands	Northern	Upper and Lower Central[1]	Middle East Coast	Lower East Coast	Lower West Coast	Upper West Coast	?	
Area 14	14A	1950	—	—	—	—	1	—	—	—	—	1
	16A	1952	—	—	—	—	5	—	—	—	1	6
	17B	1953	—	—	—	—	3	—	—	—	—	3
	17C	1953	—	—	—	—	1	—	—	—	1	2
	18B	1954	—	—	—	—	4	—	—	—	1	5
	19B	1955	—	—	—	—	55	8	1	—	27	91
	19C	1955	—	—	—	—	10	—	—	—	3	13
Area 15	13A	1949	—	—	—	—	1	—	—	—	—	1
	14C	1950	—	—	—	—	2	—	—	—	—	2
	15A	1951	—	—	—	—	2	—	—	—	1	3
	15B	1951	—	—	—	—	4	—	—	—	2	6
	17A	1953	—	—	—	—	12	2	—	—	2	16
	18A	1954	—	—	—	1	44	1	—	—	4	50
	19D	1955	—	—	—	—	87	2	—	—	25	114
	19E	1955	—	—	—	—	71	1	—	—	30	102
Lower East Coast												
Area 17A	15C	1951	—	—	—	—	1	—	—	—	1	2
	15D	1951	—	—	—	—	—	1	—	—	—	1
	16C	1952	—	—	—	—	—	1	—	—	—	1
	17E	1953	—	—	—	—	1	—	—	—	—	1
	18C	1954	—	—	—	—	14	4	—	—	8	26
	19F	1955	—	—	—	—	16	19	—	—	18	53
	19G	1955	—	—	—	—	5	56	—	1	37	99
Area 17B	15E	1951	—	—	—	—	—	2	—	—	—	2
	16F	1952	—	—	—	—	—	—	—	—	2	2
	17F	1953	—	—	—	—	—	—	—	—	2	2
	17H	1953	—	—	—	—	1	—	—	—	—	1
	17I	1953	—	—	—	—	—	1	—	—	—	1
	18D	1954	—	—	—	—	2	4	—	—	7	13
	19H	1955	—	—	—	1	1	35	1	—	29	67
	19J	1955	—	—	—	—	1	8	—	—	9	18
	19K	1955	—	—	—	1	5	35	—	—	20	61
	19L	1955	—	—	—	—	1	5	—	—	7	13
Area 18	15F	1951	—	—	—	—	—	2	—	—	—	2
	17J	1953	—	—	—	—	1	—	—	—	—	1
	18E	1954	—	—	—	—	1	7	—	—	9	17
	18F	1954	—	—	—	1	4	4	—	—	11	20
	19M	1955	—	—	—	1	1	34	3	—	19	58
Lower West Coast												
Area 23	16I	1952	—	—	—	—	—	—	1	—	—	1
	16J	1952	—	—	—	—	1	—	1	—	—	2
	17K	1953	—	—	—	—	—	—	1	—	1	2
	17M	1953	—	—	—	1	—	—	1	—	—	2
	17N	1953	—	1	—	—	—	1	—	—	1	3
	17P	1953	—	—	—	—	—	—	2	—	4	6
	17R	1953	—	—	—	—	—	—	—	—	1	1
Area 24	12L	1948	—	—	—	—	—	—	—	—	1	1
	14N	1950	—	—	—	—	—	—	—	—	1	1
	15M	1951	—	—	—	—	—	—	1	—	1	2
	15N	1951	—	—	—	—	1	—	—	—	—	1
	16M	1952	—	—	—	—	—	—	2	—	—	2
	17T	1953	—	—	—	—	—	—	2	—	2	4
	18G	1954	—	—	—	—	—	—	7	—	3	10

[1] It was impossible to separate returns from the upper and lower central sub-districts as catches from these regions were mixed freely in reduction plants. However, since the catch from the upper central sub-district was quite small in comparison with that from the lower central, it is assumed that most, if not all, of these recoveries were taken in the lower central sub-district.

Table III.—Number of Tags Recovered by Plant Crews, according to Area of Tagging and Probable Sub-district of Recovery, for the 1955–56 Fishing Season—Continued

Sub-district and Area of Tagging	Tagging Code	Year of Tagging	Probable Sub-district of Recovery									Total
			Upper Queen Charlotte Islands	Lower Queen Charlotte Islands	Northern	Upper and Lower Central[1]	Middle East Coast	Lower East Coast	Lower West Coast	Upper West Coast	?	
Upper West Coast												
Area 25	17X	1953	—	—	—	—	—	—	—	—	1	1
	18H	1954	—	—	—	—	—	2	—	—	1	3
	18J	1954	—	—	—	1	—	—	—	—	1	2
Area 26	16T	1952	—	—	—	—	—	—	—	1	—	1
	17AA	1953	—	—	—	—	—	—	—	4	2	6
	17BB	1953	—	—	—	—	—	—	—	—	1	1
Area 27	17CC	1953	—	—	—	—	—	—	—	1	—	1
United States of America												
Group 1	—	—	—	—	—	—	—	7	—	—	5	12
Group 2	—	—	—	—	—	—	—	4	—	—	5	9
Group 3	—	—	—	—	—	—	—	8	—	—	5	13
Group 4	—	—	—	—	—	—	—	1	—	—	—	1
Totals	—	—	20	628	10	436	487	262	23	7	793	2,666

[1] It was impossible to separate returns from the upper and lower central sub-districts as catches from these regions were mixed freely in reduction plants. However, since the catch from the upper central sub-district was quite small in comparison with that from the lower central, it is assumed that most, if not all, of these recoveries were taken in the lower central sub-district.

Table IV.—Probable Number of Tags in the Catches during the 1955–56 Season, Based on Magnet Recoveries, Shown by Area of Tagging and Probable Sub-district of Recovery, with Actual Number of Tags in Parentheses.

Sub-district and Area of Tagging	Probable Sub-district of Recovery								Total
	Upper Queen Charlotte Islands	Lower Queen Charlotte Islands	Northern	Central	Middle East Coast	Lower East Coast	Lower West Coast	Upper West Coast	
Upper Queen Charlotte Islands									
Area 2A (E)	85 (68)	27 (22)	11 (8)	6 (5)	2 (2)	1 (1)	—	—	132 (106)
Lower Queen Charlotte Islands									
Area 2B (E)	9 (7)	721 (614)	7 (5)	8 (7)	—	—	—	—	745 (633)
Northern									
Area 4	3 (2)	99 (85)	59 (38)	19 (16)	1 (1)	—	—	—	181 (142)
Area 5	—	43 (34)	22 (16)	12 (10)	—	1 (1)	—	—	78 (61)
Upper Central									
Area 6	5 (4)	14 (12)	11 (8)	194 (168)	5 (3)	—	—	—	229 (195)
Lower Central									
Area 7	4 (3)	43 (37)	14 (10)	393 (351)	8 (7)	6 (5)	—	—	468 (413)
Area 10	—	—	—	2 (2)	1 (1)	—	—	—	3 (3)
Upper East Coast									
Area 12	—	—	—	1 (1)	1 (1)	—	—	—	2 (2)
Middle East Coast									
Area 13	—	—	—	1 (1)	154 (144)	1 (1)	—	—	156 (146)
Area 14	—	1 (1)	—	—	125 (103)	21 (16)	1 (1)	—	148 (121)
Area 15	—	—	—	3 (2)	327 (282)	13 (10)	—	—	343 (294)
Lower East Coast									
Area 17A	—	—	—	—	51 (45)	173 (137)	—	1 (1)	225 (183)
Area 17B	—	—	—	3 (3)	17 (13)	214 (163)	1 (1)	—	235 (180)
Area 18	—	—	2 (1)	2 (2)	8 (7)	106 (84)	6 (5)	—	124 (99)
Lower West Coast									
Area 23	—	1 (1)	—	1 (1)	1 (1)	1 (1)	15 (13)	—	19 (17)
Area 24	—	—	—	—	1 (1)	—	22 (20)	—	23 (21)
Upper West Coast									
Area 25	—	1 (1)	—	1 (1)	—	3 (2)	2 (2)	—	7 (6)
Area 26	—	—	—	—	—	—	—	9 (8)	9 (8)
Area 27	—	—	—	—	—	—	—	1 (1)	1 (1)
United States of America									
San Juan Islands	—	—	—	—	—	28 (22)	—	—	28 (22)
Holmes Harbour	—	—	2 (1)	—	—	12 (10)	1 (1)	—	15 (12)
Agate Pass	—	—	—	—	—	1 (1)	—	—	1 (1)
Totals	106 (84)	950 (807)	128 (87)	646 (570)	702 (611)	581 (454)	48 (43)	11 (10)	3,172 (2,666)

Table V.—Probable Recoveries during the 1953–54, 1954–55, and 1955–56 Fisheries (Corrected for Plant Magnet Efficiency and Proportion of the Catch Searched by Plant Magnets) of Tags Inserted in Juvenile Herring on the Lower West Coast of Vancouver Island.

(The actual numbers of recoveries are given in parentheses.)

Year	Years at Large	Recovery Sub-district							Per Cent Homing
		Lower West Coast	Upper West Coast	Lower East Coast	Middle East Coast	Northern	Queen Charlotte Islands	All	
1953–54	1	3.4	—	—	—	—	—	3.4	100
		(3)						(3)	(100)
	2	1.4	—	—	—	1.3	—	2.7	52
		(1)				(1)		(2)	(50)
1954–55	1	.....	.....	.....	.....	.....	.....	.....	.....
	2	16.9	1.1	14.2	1.1	—	—	33.3	50
		(11)	(1)	(8)	(1)			(21)	(52)
	3	—	—	—	—	—	—	—	—
1955–56	2	2.8	—	—	—	—	—	2.8	100
		(2)						(2)	(100)
	3	14.6	—	8.0	—	—	1.3	23.9	61
		(10)		(5)			(1)	(16)	(62)
All years	1	3.4	—	—	—	—	—	3.4	100
		(3)						(3)	(100)
	2	21.1	1.1	14.2	1.1	1.3	—	38.8	54
		(14)	(1)	(8)	(1)	(1)		(25)	(56)
	3	14.6	—	8.0	—	—	1.3	23.9	61
		(10)		(5)			(1)	(16)	(62)

Table VI.—The Average Percentage Age Composition of the Herring Sampled from Each Major Population or Sub-district during the 1955–56 Fishing Season

(Comparable data are also given for the previous four seasons. Dominant year-classes are given in italics.)

Population and Fishing Season	In Year of Age									Average Age
	I	II	III	IV	V	VI	VII	VIII	IX+	
Upper Queen Charlotte Islands										
1951–52	.....	.....	.....	.....	.....	.....	.....	—	—	.....
1952–53	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	0.05	2.42	*27.18*	21.27	*35.10*	10.66	2.33	0.68	0.29	4.35
1954–55	.....	7.81	13.77	*40.90*	18.07	14.81	4.18	0.29	0.10	4.33
1955–56	0.10	13.81	*24.71*	20.49	23.85	9.92	5.22	1.34	0.56	4.15
Lower Queen Charlotte Islands										
1951–52	1.12	15.97	21.43	*34.55*	21.52	4.23	1.09	0.09	—	3.77
1952–53	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	.....	.....	*38.24*	*38.24*	8.82	11.76	—	2.94	—	4.06
1954–55	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1955–56	.....	0.16	15.39	9.82	*62.25*	8.62	2.89	0.70	0.17	4.76
Northern										
1951–52	0.07	4.47	8.77	*33.59*	*45.62*	6.10	1.04	0.31	0.05	4.45
1952–53	.....	1.27	*34.34*	*23.58*	*25.72*	11.03	0.98	0.08	—	4.16
1953–54	.....	1.96	*28.35*	*29.37*	*23.80*	13.33	2.54	0.58	0.06	4.28
1954–55	.....	2.78	4.90	*70.78*	15.32	5.02	1.04	0.15	—	4.18
1955–56	.....	8.85	*56.30*	9.77	*20.84*	3.28	0.62	0.19	0.14	3.57
Upper Central										
1951–52	0.15	7.09	16.75	23.60	*45.72*	4.93	1.54	0.22	—	4.30
1952–53	0.70	6.94	*24.74*	*24.39*	*28.49*	14.06	0.68	.....	.....	4.18

Table VI.—The Average Percentage Age Composition of the Herring Sampled from Each Major Population or Sub-district during the 1955–56 Fishing Season—Continued

(Comparable data are also given for the previous four seasons. Dominant year-classes are given in italics.)

Population and Fishing Season	In Year of Age									Average Age
	I	II	III	IV	V	VI	VII	VIII	IX+	
1953–54	0.42	5.12	*74.47*	14.11	4.93	0.94	—	—	—	3.21
1954–55	0.06	12.53	18.82	*63.43*	4.08	0.87	0.21	—	—	3.62
1955–56	—	*84.74*	12.72	1.26	1.14	0.15	—	—	—	2.19
Lower Central										
1951–52	1.99	5.59	*25.14*	*33.53*	*27.66*	3.89	1.49	0.64	0.07	4.00
1952–53	0.40	9.14	*28.13*	*24.04*	*26.69*	9.70	1.42	0.48	—	4.05
1953–54	0.18	5.52	*70.41*	18.00	4.39	1.32	0.13	—	0.04	3.26
1954–55	0.39	5.74	10.20	*69.83*	10.86	2.65	0.33	—	—	3.94
1955–56	0.03	7.64	13.76	9.96	*64.71*	3.46	0.38	0.03	0.02	4.44
Upper East Coast										
1951–52	*43.17*	*20.22*	13.12	10.65	7.93	3.23	1.12	0.50	0.50	2.37
1952–53	—	—	1.14	20.45	*36.36*	28.41	9.09	2.27	2.27	5.40
1953–54	0.16	9.31	*65.87*	15.20	6.61	2.32	0.45	0.08	—	3.28
1954–55	0.17	4.66	*34.37*	*45.23*	10.10	3.36	1.58	0.54	—	3.80
1955–56	—	16.84	17.15	19.45	*41.16*	5.40	—	—	—	4.01
Middle East Coast										
1951–52	0.25	*32.61*	*45.82*	14.18	5.44	1.57	0.06	0.06	—	2.97
1952–53	0.60	*30.99*	*41.18*	17.00	6.30	3.16	0.66	0.10	—	3.10
1953–54	—	2.48	*28.59*	*40.98*	18.82	6.77	1.91	0.39	0.05	4.06
1954–55	—	6.02	*37.71*	*45.88*	8.25	2.01	0.12	—	—	3.63
1955–56	—	9.39	13.08	*28.68*	*39.14*	7.78	1.37	0.40	0.16	4.29
Lower East Coast										
1951–52	0.04	6.62	*57.51*	27.14	6.99	1.31	0.31	0.07	0.01	3.40
1952–53	0.12	2.65	*60.53*	32.83	3.25	0.54	0.05	0.03	—	3.38
1953–54	—	0.79	*57.98*	34.23	6.18	0.62	0.14	0.04	0.01	3.48
1954–55	—	2.81	*57.18*	33.37	6.05	0.50	0.10	—	—	3.45
1955–56	—	4.37	*53.07*	29.86	10.70	1.71	0.24	0.05	—	3.53
Lower West Coast										
1951–52	0.06	5.21	*65.71*	20.08	7.94	0.83	0.17	—	—	3.34
1952–53	0.07	8.88	*55.66*	32.86	1.95	0.54	0.04	—	—	3.30
1953–54	0.03	2.72	*64.29*	26.71	5.47	0.53	0.14	0.07	0.04	3.38
1954–55	0.03	16.82	*59.39*	19.81	3.32	0.59	0.03	—	—	3.11
1955–56	—	11.87	*63.70*	15.86	7.04	1.29	0.14	0.04	0.05	3.23
Upper West Coast										
1951–52	—	0.19	10.11	*27.23*	*52.54*	7.32	2.12	0.42	0.05	4.65
1952–53	0.26	22.57	*60.74*	14.60	1.35	0.40	0.07	—	—	2.96
1953–54	—	—	*46.14*	*41.85*	9.04	2.04	0.94	—	—	3.70
1954–55	—	6.24	34.57	*50.40*	6.78	1.68	0.26	0.07	—	3.64
1955–56	—	—	—	—	—	—	—	—	—	—

Table VII.—Number of Fish (in Millions) of Each Age in the Catch from Each Population during the Past Five Fishing Seasons

(Dominant year-classes are given in italics.)

Population and Fishing Season	In Year of Age									Total
	I	II	III	IV	V	VI	VII	VIII	IX+	
Upper Queen Charlotte Islands										
1951–52[1]	—	—	—	—	—	—	—	—	—	—
1952–53[1]	—	—	—	—	—	—	—	—	—	—
1953–54	0.12	7.43	*83.61*	65.44	*107.98*	32.78	7.17	2.08	0.89	307.50
1954–55	—	16.32	28.74	*85.36*	37.71	30.91	8.72	0.60	0.38	208.74
1955–56	0.07	9.59	*17.16*	14.23	*16.57*	6.89	3.62	0.93	0.39	69.45

[1] No catch.

Table VII.—Number of Fish (in Millions) of Each Age in the Catch from Each Population during the Past Five Fishing Seasons—Continued

(Dominant year-classes are given in italics.)

Population and Fishing Season	In Year of Age									Total
	I	II	III	IV	V	VI	VII	VIII	IX+	
Lower Queen Charlotte Islands										
1951–52	1.24	18.03	24.18	*38.99*	24.29	4.77	1.23	0.10	.....	112.83
1952–53[2]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	.....	.....	7.23	7.23	1.67	2.22	.....	0.56	.....	18.91
1954–55[3]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1955–56	.....	1.05	100.91	64.39	*408.15*	56.52	18.95	4.59	1.11	655.67
Northern										
1951–52	0.24	19.44	38.12	*145.91*	*198.17*	26.51	4.51	1.35	0.21	434.46
1952–53	.....	0.23	6.87	4.34	4.73	2.02	0.18	0.02	.....	18.39
1953–54	.....	4.87	*70.77*	*73.33*	59.42	33.28	6.34	1.45	0.14	249.60
1954–55	.....	5.09	8.98	*129.86*	28.11	9.21	1.91	0.27	.....	183.43
1955–56	.....	10.78	*68.57*	11.90	*25.38*	4.00	0.76	0.23	0.17	121.79
Upper Central										
1951–52	0.26	12.31	24.02	32.84	*63.39*	6.88	2.13	0.31	.....	142.14
1952–53	0.01	0.06	0.21	0.21	0.24	0.12	0.01	.....	.....	0.86
1953–54	0.44	5.30	*77.14*	14.14	5.11	0.97	.....	.....	.....	103.10
1954–55	0.63	14.53	21.81	*73.50*	4.73	1.01	0.24	.....	.....	116.45
1955–56	.....	*32.12*	4.82	0.48	0.43	0.06	.....	.....	.....	37.91
Lower Central										
1951–52	3.35	9.15	*41.86*	*56.09*	*46.30*	6.52	2.50	1.08	0.13	166.98
1952–53	0.04	0.99	2.66	2.14	2.17	0.78	0.09	0.03	.....	8.90
1953–54	0.41	13.94	*234.14*	66.51	15.85	3.49	0.48	.....	0.16	334.98
1954–55	0.72	14.26	25.86	*125.38*	19.85	4.63	0.48	.....	.....	191.18
1955–56	0.14	20.74	47.11	36.91	*242.67*	12.59	1.35	0.14	0.11	361.76
Upper East Coast										
1951–52	*65.59*	*30.71*	19.92	16.17	12.04	4.91	1.70	0.76	0.07	151.87
1952–53[4]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	0.13	8.60	*60.90*	14.05	6.11	2.15	0.41	0.07	.....	92.42
1954–55	0.24	9.06	*49.67*	*75.13*	18.15	3.24	0.64	0.22	.....	156.35
1955–56	.....	1.87	1.90	2.16	*4.57*	0.60	.....	.....	.....	11.10
Middle East Coast										
1951–52	0.34	*39.74*	*55.84*	17.28	6.63	1.91	0.07	0.07	.....	121.88
1952–53[5]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	.....	4.40	*50.42*	*70.08*	27.55	10.47	2.78	0.59	0.07	166.36
1954–55	.....	15.44	*95.15*	*112.83*	20.03	5.04	0.21	.....	.....	248.70
1955–56	.....	28.97	36.00	*73.94*	*96.90*	18.92	3.25	0.91	0.34	259.23
Lower East Coast										
1951–52	0.23	29.52	*201.13*	83.93	23.54	4.30	1.24	0.29	0.06	344.24
1952–53	0.12	2.00	*51.59*	30.51	2.98	0.51	0.06	0.03	.....	87.80
1953–54	.....	3.54	*283.14*	167.41	29.55	3.02	0.67	0.20	0.09	487.62
1954–55	.....	13.55	*261.95*	151.56	26.41	2.22	0.31	.....	.....	456.00
1955–56	.....	20.75	*246.47*	137.66	48.26	7.36	1.07	0.16	.....	461.73
Lower West Coast										
1951–52	0.06	5.84	*73.56*	22.44	8.89	0.91	0.20	.....	.....	111.90
1952–53[6]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	0.27	7.92	*194.15*	86.22	18.36	1.98	0.58	0.21	0.12	309.81
1954–55	0.02	11.86	*41.89*	13.97	2.34	0.42	0.02	.....	.....	70.52
1955–56	.....	25.00	*129.16*	30.65	8.36	1.47	0.27	0.07	0.03	195.01
Upper West Coast										
1951–52	.....	0.23	12.87	*34.65*	*66.85*	9.31	2.70	0.53	0.06	127.20
1952–53[7]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	.....	.....	*42.42*	*39.80*	9.03	2.19	1.02	.....	.....	94.46
1954–55	.....	3.95	21.62	*31.07*	4.32	0.92	0.17	0.04	.....	62.09
1955–56[8]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[2] One hundred and eighty-five tons caught; no samples obtained.
[3] Five hundred and fifty tons caught; no samples obtained.
[4] One hundred and three tons caught; no samples obtained.
[5] Eighty-three tons caught; no samples obtained.
[6] Twenty-three tons caught; no samples obtained.
[7] Five hundred and sixty tons caught; no samples obtained.

Table VIII.—The Average Length in Millimetres of the Herring Sampled from Each Major Population or Sub-district during the 1955–56 Fishing Season

(Comparable data are also given for the previous four seasons.)

Population and Fishing Season	In Year of Age									
	I	II	III	IV	V	VI	VII	VIII	IX	X
Upper Queen Charlotte Islands										
1951–52										
1952–53										
1953–54	122.00	132.53	165.58	175.69	197.14	208.13	216.68	231.09	236.33	262.00
1954–55		147.28	162.59	184.32	201.68	214.50	228.87	243.67	237.00	244.00
1955–56	97.00	139.06	159.54	176.27	200.62	213.52	223.70	231.54	236.50	254.00
Lower Queen Charlotte Islands										
1951–52	101.41	150.98	180.21	194.11	202.42	212.45	218.13	213.50		
1952–53										
1953–54			178.85	197.23	204.67	221.25		228.00		
1954–55										
1955–56		160.50	186.19	197.74	203.16	215.06	221.92	224.50		
Northern										
1951–52	119.67	155.65	182.48	200.15	206.92	216.09	222.84	224.76	253.50	
1952–53		149.41	182.72	200.95	210.98	215.87	222.00	217.00		
1953–54		144.30	177.12	200.98	215.88	223.45	232.42	238.88	230.00	250.00
1954–55		155.58	181.53	193.91	205.37	218.03	222.23	229.00		
1955–56		145.40	176.76	190.39	200.03	211.48	217.89	230.67	237.50	
Upper Central										
1951–52	108.50	156.42	187.75	203.35	210.92	218.72	221.58	226.33		
1952–53	105.50	149.50	192.96	208.01	215.63	223.44	228.00			
1953–54	122.00	146.96	165.24	182.90	198.12	214.00				
1954–55	128.00	145.76	162.18	179.17	193.65	188.23	219.33			
1955–56		147.11	161.38	170.43	200.29	235.00				
Lower Central										
1951–52	107.95	144.86	181.64	199.94	210.81	219.62	225.10	225.50	238.50	
1952–53	119.18	148.11	185.36	200.22	210.70	219.58	226.59	232.62		
1953–54	112.22	126.59	158.15	184.06	195.62	203.75	211.67		222.00	
1954–55	103.24	132.66	161.46	180.63	194.64	201.68	207.08			
1955–56	114.00	143.07	180.16	196.47	205.18	212.24	217.56	208.50		235.00
Upper East Coast										
1951–52	99.80	143.92	180.42	195.06	207.44	215.40	222.54	226.77		249.00
1952–53										
1953–54	114.25	132.35	154.67	179.24	202.62	224.82	231.91	237.50		
1954–55	101.00	135.61	159.13	165.32	178.41	207.92	225.85	227.71		
1955–56		115.79	135.67	162.90	198.98	207.37				
Middle East Coast										
1951–52	103.25	142.52	176.93	196.52	207.00	219.25	216.00	221.00		
1952–53	107.75	138.73	177.93	199.05	215.77	224.58	228.62	229.00		
1953–54		148.32	174.03	196.28	213.68	224.26	230.88	236.33	269.00	
1954–55		150.12	176.53	190.15	204.99	215.95	227.67			
1955–56		147.03	181.72	198.00	206.06	217.56	226.83	234.36	238.20	246.00
Lower East Coast										
1951–52	96.33	150.84	185.46	198.36	208.93	216.92	225.61	226.60	222.00	
1952–53	106.50	155.94	183.81	195.96	208.64	214.45	222.80	233.33		
1953–54		151.97	187.22	199.49	210.70	222.89	226.70	227.33	237.00	
1954–55		163.09	188.88	199.58	210.63	225.25	238.33			
1955–56		160.16	186.44	198.36	208.26	215.85	224.08	230.50		
Lower West Coast										
1951–52	131.00	158.41	186.16	198.38	212.19	221.14	225.67			
1952–53	97.00	162.12	184.02	197.83	209.41	219.20	211.00			
1953–54	90.50	160.53	185.34	199.81	211.16	222.52	241.38	239.50	271.00	278.00
1954–55	140.00	164.34	182.31	198.64	210.38	221.81	220.00			
1955–56		165.12	185.74	197.71	204.18	216.46	227.71	233.00	221.00	
Upper West Coast										
1951–52		167.14	191.18	207.42	217.49	225.96	231.84	236.53	240.00	
1952–53	99.50	145.86	187.81	199.25	207.10	228.50	233.00			
1953–54			181.01	198.05	210.71	222.64	231.83			
1954–55		153.97	180.52	194.96	210.04	216.21	230.75	236.00		
1955–56										

Table IX.—The Average Weight in Grams of the Herring Sampled from Each Major Population or Sub-district during the 1955–56 Fishing Season

(Comparable data are also given for the previous four seasons.)

Population and Fishing Season	In Year of Age									
	I	II	III	IV	V	VI	VII	VIII	IX	X
Upper Queen Charlotte Islands										
1951–52										
1952–53										
1953–54	20.00	25.09	50.84	67.00	95.17	110.89	131.87	154.36	143.33	145.00
1954–55		39.93	57.78	85.52	114.52	135.16	163.38	174.33	215.00	200.00
1955–56	13.00	32.03	54.12	74.38	111.42	137.12	154.60	173.46	155.00	249.00
Lower Queen Charlotte Islands										
1951–52	9.11	38.63	76.38	100.64	116.16	136.32	153.38	143.00		
1952–53										
1953–54			68.00	93.08	105.33	150.75		170.00		
1954–55										
1955–56		43.00	87.54	109.14	121.15	147.42	163.11	166.30		
Northern										
1951–52	22.00	46.31	83.87	115.90	130.68	150.11	165.77	166.35	221.50	
1952–53		38.82	80.31	110.76	130.68	143.32	157.22			
1953–54		35.98	71.76	105.91	130.77	145.19	164.32	182.62	193.00	181.00
1954–55		40.36	79.53	95.62	114.41	138.24	147.00	154.00		
1955–56		37.13	76.33	94.38	113.70	140.48	151.78	170.00	199.00	
Upper Central										
1951–52	14.75	47.50	88.57	114.91	130.23	145.29	155.92	165.00		
1952–53	10.50	35.05	91.93	118.41	135.96	153.41	169.00			
1953–54	20.50	41.83	60.22	85.68	108.21	138.80				
1954–55	28.00	41.27	64.10	84.16	105.14	97.15	156.67			
1955–56		40.95	60.03	70.57	112.29	155.00				
Lower Central										
1951–52	14.51	37.86	80.20	109.68	132.40	150.63	160.10	161.06	173.00	
1952–53	18.00	35.72	82.37	106.57	126.10	146.07	160.91	169.86		
1953–54	17.44	26.74	53.09	84.18	101.66	115.69	125.50		131.00	
1954–55	14.06	30.49	60.02	85.31	108.54	124.25	126.23			
1955–56	15.50	36.03	83.16	110.31	126.40	141.15	155.83	122.00		180.00
Upper East Coast										
1951–52	11.05	35.79	74.36	99.12	122.71	141.50	159.36	157.50		
1952–53										
1953–54	17.50	34.90	56.37	85.03	117.04	154.40	157.45	183.00		
1954–55	14.00	32.84	61.17	66.78	86.25	134.53	170.05	186.29		
1955–56		17.89	32.97	62.38	116.10	127.16				
Middle East Coast										
1951–52	14.00	39.51	80.81	114.82	141.00	170.79	178.00	143.00		
1952–53	11.91	29.84	69.59	103.04	134.00	161.45	165.00	156.00		
1953–54		42.59	70.65	104.41	142.57	166.83	183.69	195.94	185.00	
1954–55		45.24	79.54	94.34	124.42	144.78	167.00			
1955–56		42.84	79.54	105.58	120.02	141.82	160.66	177.89	174.80	186.50
Lower East Coast										
1951–52	11.33	46.06	91.25	113.54	138.55	157.65	175.39	172.60	178.00	
1952–53	12.83	44.89	76.78	93.56	118.66	135.30	146.40	185.00		
1953–54		46.36	88.41	107.69	127.25	148.66	157.50	181.00	186.00	
1954–55		56.64	94.08	113.45	131.96	163.44	178.33			
1955–56		51.36	85.16	105.53	124.75	140.22	161.92	173.00		
Lower West Coast										
1951–52	30.00	52.53	89.63	108.79	138.84	159.64	170.00			
1952–53	8.50	51.67	78.83	100.06	121.18	143.60	123.00			
1953–54	8.50	53.72	85.55	106.65	126.75	148.35	165.75	155.00		
1954–55	37.00	57.83	83.06	107.68	124.91	151.40	131.00			
1955–56		57.40	85.99	106.64	119.25	138.89	144.00		140.00	
Upper West Coast										
1951–52		57.00	89.49	117.11	138.46	156.48	169.66	179.50	190.00	
1952–53	9.75	36.23	82.27	100.25	114.70	158.50	168.00			
1953–54			77.41	98.51	123.85	143.25	145.00			
1954–55		46.44	84.59	104.91	134.67	141.86	180.67	174.00		
1955–56										

Table X.—Average Sex Ratio (Females/Males) in Populations of Herring on the British Columbia Coast during the Past Five Fishing Seasons

Population	Fishing Season					
	1951–52	1952–53	1953–54	1954–55	1955–56	Average
Upper Queen Charlotte Islands	—	—	1.05	1.05	1.18	1.09
Lower Queen Charlotte Islands	0.96	—	0.48[1]	—	1.00	.98
Northern	0.98	0.88	1.12	1.12	1.04	1.03
Upper Central	1.05	1.13	1.02	1.15	1.23	1.12
Lower Central	1.10	1.37	0.96	1.16	1.15	1.15
Upper East Coast	0.84	1.00	1.07	1.12	1.10	1.03
Middle East Coast	0.80	1.02	1.01	1.24	1.15	1.04
Lower East Coast	0.88	0.84	0.81	0.92	1.04	.90
Lower West Coast	1.04	1.06	1.07	1.07	0.93	1.03
Upper West Coast	1.02	1.24	1.08	1.15	—	1.12
Average	0.96	1.06	1.02	1.11	1.09	1.05

[1] Based on only thirty-four fish and so emitted from averages.

Table XI.—Number of Statutory Miles of Herring Spawn Deposited in British Columbia Waters in 1956, Adjusted to Medium Intensity by Area and Year

(Comparable data are also given for the preceding four years. Figures in parentheses include surveys carried out by Biological Station personnel.)

Sub-district and Area	Statutory Miles of Spawn of Medium Intensity				
	1952	1953	1954	1955	1956
Upper Queen Charlotte Islands					
Area 2A (E) (Skidegate Inlet)	0.8	3.2	1.9	----	----
Lower Queen Charlotte Islands					
Area 2B (E) (Skincuttle Inlet)	4.6	10.2	20.2	11.3	9.7
Northern					
Area 3 (Nass)	1.6	0.9	0.5	----	2.6
Area 4 (Skeena)	11.6	16.1	5.4	4.3	5.8
Area 5 (Grenville)	0.9	3.3	10.5	18.8	11.9
Totals	14.1	20.3	16.4	23.1	20.3
Upper Central					
Area 6 (Butedale)	4.3	6.8	4.7	4.0	0.3
Lower Central					
Area 7 (Bella Bella)	17.7	29.4	28.0	28.2	18.8
Area 8 (Bella Coola)	1.5	0.2	2.7	8.9	1.4
Area 9 (Rivers Inlet)	0.8	4.2	0.4	1.1	0.1
Area 10 (Smith Inlet)	2.8	9.2	5.8	1.6	4.1
Totals	22.8	43.0	36.9	39.8	24.4
Upper East Coast of Vancouver Island					
Area 11 (Seymour Inlet)	0.2	----	0.4	----	----
Area 12 (Alert Bay)	9.7	24.7	14.0	9.2	15.9
Totals	9.9	24.7	14.4	9.2	15.9
Middle East Coast of Vancouver Island					
Area 13 (Campbell River)	6.0	5.8	3.2	12.2 (13.8)	---- (5.3)
Area 14 (Comox)	24.4	23.7	11.4	19.0 (21.0)	21.7 (22.6)
Area 15 (Powell River)	2.3	3.0	2.4	1.4 (1.6)	---- (----)
Area 16 (Pender Harbour)	3.4	3.2	4.8	4.0 (4.0)	2.1 (----)
Totals	36.1	35.7	21.8	36.6 (40.4)	23.8 (27.9)
Lower East Coast of Vancouver Island					
Area 17A (Nanaimo)	7.8	17.6	0.8	9.0 (9.4)	3.0 (4.2)
Area 17B (Ladysmith)	20.4	82.4	61.5	6.5 (28.8)	9.4 (7.7)
Area 18 (Ganges Harbour)	2.0	2.5	1.9	1.4 (5.2)	1.8 (9.1)
Area 19 (Victoria)	0.1	----	----	---- (----)	---- (----)
Totals	30.3	102.5	64.2	16.9 (43.4)	14.2 (21.0)
Lower West Coast of Vancouver Island					
Area 23 (Barkley Sound)	4.8 (9.8)	7.8 (13.1)	4.6 (11.0)	5.6	13.4
Area 24 (Clayoquot Sound)	4.9 (2.4)	7.0 (7.8)	4.2 (4.5)	4.7	1.1
Totals	9.7 (12.2)	14.8 (20.9)	8.8 (15.5)	10.3	14.5
Upper West Coast of Vancouver Island					
Area 25 (Esperanza Inlet)	2.8 (26.6)	11.4 (36.4)	7.1 (17.5)	6.9	53.2
Area 26 (Kyuquot Sound)	0.9 (1.6)	4.4 (8.0)	3.2 (4.8)	8.6	0.9
Area 27 (Quatsino Sound)	1.2 (1.3)	10.8 (11.5)	7.2 (7.3)	2.6	----
Totals	4.9 (29.5)	26.6 (55.9)	17.5 (29.6)	18.1	54.1
Grand totals, all areas	137.5 (164.6)	287.8 (323.2)	206.8 (225.6)	169.3 (199.6)	177.2 (188.1)

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Contributions to the Life-history of the Sockeye Salmon

[PAPER 41.]

BY

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APPENDICES

CONTRIBUTIONS TO THE LIFE-HISTORY OF THE SOCKEYE SALMON (No. 41)

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INTRODUCTION

This is the forty-first report in a series reporting on the sockeye in the commercial catch in the main runs north of the Fraser River. The data presented are, for the most part, those for the commercial fishery and do not necessarily represent the escapement. Whenever the opportunity arose, escapement figures were obtained and compared with those of the catch. The numbers of sockeye in the catch, as shown in the tables, were obtained through the statistical branch of the Department of Fisheries at Vancouver.

DESIGNATION OF AGE-GROUPS AND TREATMENT OF DATA

Two outstanding features in the life-history of the fish have been selected in designating the age-groups—namely, the age at maturity and the year of its life in which the fish migrated from fresh water. These are expressed symbolically by two numbers—one in large type, which indicates the age of maturity, and the other in small type, placed to the right and below, which signifies the year of life in which the fish left fresh water. The age-groups which are met most commonly are:—

3_1, 4_1—the " sea types " or fish which migrate seaward in their first year and mature in their third and fourth year respectively.

3_2—" the grilse," almost exclusively males and frequently called " jacks," which migrate seaward in their second year and mature in their third year.

4_2, 5_2—fish which migrate seaward in their second year and mature in their fourth and fifth years respectively.

5_3, 6_3—fish which migrate seaward in their third year and mature in their fifth and sixth years respectively.

6_4, 7_4—fish which migrate seaward in their fourth year and mature in their sixth and seventh years respectively.

Fish were measured to the nearest quarter of an inch, but when averaged the average has been recorded to the nearest tenth of an inch to avoid using fractions of more than one decimal place. Weights were taken to the nearest tenth of a pound. This has resulted in an even-pound and half-pound bias when the data are grouped to the nearest quarter-pound.

1. THE NASS RIVER SOCKEYE RUN OF 1955

(1) General Characteristics

The catch of 154,904 sockeye, which yielded a pack of 13,654 cases (Table I), was considerably below the five-year average (1951 to 1955) of 19,200 cases, and even below the ten-year average (1946 to 1955) of 16,909 cases. This pack resulted chiefly from a run (1950) which yielded a pack of 27,286 cases. The escapement was reported as satisfactory that year.

(2) Age-groups

The Nass River sockeye-catch sample contained 12 per cent 4-year fish, 85 per cent 5-year fish, and 2 per cent 6-year fish (Table I). Of these fish, 27 per cent had spent one year in fresh water and had migrated seaward in the beginning of their second year; 72 per cent had spent two years in fresh water and had migrated to sea at the beginning of their third year (Table I). A few fish, which had apparently migrated to sea as fry, returned in their third or fourth year (Tables II and III).

(3) Lengths and Weights

The average lengths recorded for the main age-groups of the year's sample were less than those recorded at any time in the past ten years, except in the 6_3 males (Table IV). In this last group, only the samples of 1949 and 1950 had smaller average lengths. However, in weight, this year's samples were no lower than the lowest weights recorded during the past ten years (Table V). In no case could the sockeye samples be considered as anything but small fish for this area.

(4) Distribution of Sexes

The Nass River sockeye sample was 49 per cent males and 51 per cent females, with the percentage of males varying in the individual age-groups as follows: 4_2, 50 per cent; 5_2, 60 per cent; 5_3, 47 per cent; and 6_3, 68 per cent (Table VI).

2. THE SKEENA RIVER SOCKEYE RUN OF 1955

(1) General Characteristics

Due to the low catch of 157,632 sockeye, yielding only 14,649 cases (Table VII), the Skeena River sockeye runs have dropped from the ten-year average (1945 to 1954) of 70,671 cases to a ten-year average (1946 to 1955) of 61,708 cases. Since, however, this drop is believed to be directly due to the loss of spawners caused by the Babine River slide, it is not a serious cause for alarm, since, with the removal of the slide and the curtailed seasons being put into effect by the Federal Department of Fisheries and the Committee on Management, Skeena River Salmon Fisheries, the situation should right itself.

(2) Age-groups

Five-year-old fish formed 73 per cent of the Skeena River sockeye-catch sample, 59 per cent having spent one year in fresh water and 14 per cent two years (Table VII). There were 15 per cent 4_2 fish and 11 per cent 6_3 fish. It must be realized that these figures might have been somewhat altered if fishing had progressed evenly throughout the run. However, a total closure during the week ended July 30th and a partial closure in the week ended August 6th were imposed to permit a more adequate escapement. Test fishing above the boundary with commercial nets and with graded series of mesh sizes was carried out. While the catch from this fishing is generally considered to be from the escapement, there is a movement of as yet undetermined extent, back and forth, which undoubtedly exposes some of the fish to the fishery again after they have passed the commercial boundary. The age-class composition of the sockeye taken in the test fishing was, in round numbers, 6 per cent 3_2 fish, 25 per cent 4_2 fish, 53 per cent 5_2 fish, 7 per cent 5_3 fish, and 8 per cent 6_3 fish (Table XXV). As can be seen from a comparison of Tables XXV and XXVI, this varies from the commercial catch chiefly in having a greater percentage of jacks and 4-year-old fish and small percentage of 5- and 6-year fish. The significance of this will be discussed below when the lengths of these fish are considered.

(3) Lengths and Weights

From Tables X and XI it is noted that the Skeena River sockeye in 1955 were in the lower part of the normal size range in all the main age-classes. The lengths and weights in the main age-groups were as follows:—

The 4_2 sockeye males averaged 22.5 inches and 4.9 pounds, and the females 22.1 inches and 4.8 pounds. Averages for the 5_2 sockeye were 25.6 inches and 7.4 pounds for the males, and 24.5 inches and 6.4 pounds for the females. In the 5_3 fish, the males averaged 23.0 inches and 5.5 pounds, while the females averaged 22.6 inches and 5.0 pounds. The 6_3 sockeye averaged 25.2 inches and 7.1 pounds for the males and 24.0 inches and 6.1 pounds for the females.

When the above lengths are compared with those obtained from the test fishing, as shown below, certain features stand out. It is at once evident that the age-groups in the escapement sample have lower average lengths than those in the commercial catch sample. When comparing the abundance of each age-group in the two samples, it is readily seen that a greater proportion of the age-groups which are made up of the smaller fish, the 3_2 and 4_2 groups, is in the escapement than in the catch. Tables XXV and XXVI show more detail on the length distribution of the escapement and the catch than the following table:—

Age-group	Catch (604 Fish)		Escapement (1,094 Fish) (Test Fishing)	
	Length	Per Cent of Sample	Length	Per Cent of Sample
3_2	16.1	0.3	15.7	6.2
4_2	22.3	14.7	21.7	25.1
5_2	24.9	59.1	24.6	52.7
5_3	22.8	13.9	22.5	7.2
6_3	24.6	11.3	24.7	8.1

It is not known what effect allowing a large proportion of the escapement to come from the smaller fish from an age-group will have on the future size of that age-group. However, the fact that certain runs maintain size differences from adjacent runs indicates that hereditary factors are probably involved to a considerable extent. If so, the folly of allowing the smaller fish to form the escapement from which our future stocks must come is obvious.

(4) Distribution of Sexes

The distribution of sexes in the Skeena River sockeye-catch shows two trends which are almost invariable. These are that the catch as a whole contains over 50 per cent females and the catch of 5_2 age-group fish contains an even greater percentage of females than the total catch. This year was no exception, since 53 per cent of the sockeye sample consisted of females and 58 per cent of the 5_2 fish were females (Table XII). Only 43 per cent of the 4_2 age-group sample were females. This is the lowest percentage of 4_2 females recorded in the catch samples in over three cycles (Table XII).

3. THE RIVERS INLET SOCKEYE RUN OF 1955

(1) General Characteristics

The catch of 584,128 sockeye, yielding 50,702 cases (Table XIII), was an extreme disappointment in a year when it was expected that the catch would be amongst the largest recorded. From the catch sample, it was obvious that the main failure was in the lack of adequate returns of 5-year fish from the 1950 spawning, when, to quote from the Federal Department of Fisheries "Salmon-spawning Report, British Columbia, 1950," by Chief Supervisor A. J. Whitmore, "a large escapement of predominantly large sockeye is reported."

Unfortunately, no information on conditions in the spawning area in the winter after egg deposition is available, so that no reason for the failure can be ascertained. If lake-level and temperature recorders were set up in the main Owikeno Lake spawning areas, conditions likely to cause widespread destruction of eggs in the redds would not recur without some knowledge of them being available to those interested.

(2) Age-groups

The Rivers Inlet sockeye-catch sample in 1955 was composed of 45 per cent 4_2 fish and 54 per cent 5_2 fish, with minor numbers of 5_3 and 6_3 age-groups (Table XIII). From spawning reports of 1950 and 1951, it had been presumed that the 5_2 age-group would comprise a very much higher proportion of the run. The low catch of 1955 is largely attributable to the failure of the return from the 1950 spawning.

Through the courtesy of the Fish Culture Development Branch, the author was able to sample sockeye seined above the fishing boundary in connection with spring-salmon tagging operations. These fish would bear the same relationship to the escapement as the sockeye caught in the Skeena test fishing mentioned previously. In addition, a sample of the escapement was obtained on some of the spawning-streams. The comparison of the percentages in these two samples and the commercial catch sample is interesting in that it shows that the younger age-classes (jacks and 4_2 fish) form a larger percentage of the escapement than of the catch.

	Age-class				
	Jacks (3_2, 4_3)	4_2	5_2	5_3	6_3
	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
Catch (685 fish)	0.0	44.8	54.2	0.4	0.6
Escapement seined (231 fish)	1.3	78.8	19.5	0.0	0.4
On redds (165 fish)	6.4	52.6	41.0	0.0	0.0

(3) Lengths and Weights

As was the case with the Nass and Skeena River runs, the Rivers Inlet sockeye were within the range of lengths and weights as recorded in previous years. The average length for the 4_2 male sockeye was 21.2 inches, and for the females, 21.0 inches; for the 5_2 age-group the lengths were 25.4 inches and 24.5 inches respectively (Table XXVI). Average weights in these classes were: 4_2 males, 4.5 pounds, and females, 4.2 pounds; and 5_2 males, 7.4 pounds, and females, 6.5 pounds (Table XXVII).

Comparison of the length of the sockeye in the catch and escapement samples is also interesting, as shown below (lengths taken to nearest quarter inch).

	Age-class				
	Jacks (3_2, 4_3)	4_2	5_2	5_3	6_3
	Inches	Inches	Inches	Inches	Inches
Catch sample (685 fish)	14¾	21¼	24¾	22	25
Escapement seined (231 fish)	14¾	19¾	25	—	—
On redds[1] (165 fish)	14¾	19½	25¼	—	—

[1] This sample was divided into age-classes on the basis of length. The 5_3 and 6_3 fish present would be indistinguishable from the larger 4_2 and 5_2 fish, and so no attempt was made to separate out these classes.

The tabulated data show clearly that the escapement comes from the smaller 4_2 fish and the larger 5_2 fish, though the tendency in this latter case is not as striking as in the former, where the average length of the catch is 1½ inches greater than in the escapement.

(4) Distribution of Sexes

The sex distribution, as related to age, again showed the invariable relationship of more males amongst the 4-year-old fish and more females in the 5-year-old fish in the catch samples (Table XVIII). Percentage of males was 67 in the 4_2 fish and 31 in the 5_2 fish. The over-all percentage of males was 48.

4. THE SMITH INLET SOCKEYE RUN OF 1955

(1) General Characteristics

Though less than the average for the past five years, the catch of 325,478 sockeye, yielding 28,864 cases, was slightly above the Smith Inlet average of 27,926 cases for the past ten years. This is in direct contrast to the poor showing of the adjacent Rivers Inlet catch. Though, in general, Smith Inlet runs behave similarly to Rivers Inlet runs, recording instruments in both spawning areas at times of differing conditions would materially add to our knowledge and our ability to predict returns in these areas.

(2) Age-groups

As is normal in this run, only two main age-groups were present; 4_2 fish formed 42 per cent of the catch sample and 5_2 fish 58 per cent (Tables XIX to XXI). One 5_3 fish was present (Tables XX and XXI).

(3) Lengths and Weights

As with the other samples, the Smith Inlet sockeye were in the lower part of the length and weight ranges of former years, but set no records. The 4_2 fish had averages of 21.8 inches and 5.0 pounds for the males and 21.6 inches and 4.7 pounds for the females, while the 5_2 fish had averages of 25.3 inches and 7.5 pounds and 24.6 inches and 6.9 pounds respectively for the males and females (Tables XXII and XXIII).

(4) Sex Distribution

The Smith Inlet sockeye catch sample showed its usual sex distribution, with 76 per cent of the 4_2 fish and 37 per cent of the 5_2 fish being males (Table XXIV). In the over-all sample, there were 54 per cent males.

Table I.—Nass River Sockeyes, Percentages of Principal Age-groups in Runs of Successive Years and Packs

Year	Pack in Cases	Number of Sockeye[1]	Percentage of Individuals			
			4_2	5_2	5_3	6_3
1912	36,037	.....	8	27	63	2
1913	23,574	.....	15	12	71	2
1914	31,327	.....	4	41	45	10
1915	39,349	.....	19	14	59	8
1916	31,411	.....	9	17	66	8
1917	22,188	.....	10	15	71	4
1918	21,816	.....	30	16	45	9
1919	28,259	.....	7	22	65	6
1920	16,740	.....	8	14	72	6
1921	9,364	.....	10	7	75	8
1922	31,277	.....	6	2	91	1
1923	17,821	.....	11	6	77	6
1924	33,590	.....	4	3	91	2
1925	18,945	.....	23	8	67	2
1926	15,929	.....	12	12	63	13
1927	12,026	.....	8	7	81	4
1928	5,540	.....	30	6	61	3
1929	16,077	.....	25	9	60	6
1930	26,405	.....	28	15	54	3
1931	16,929	.....	10	17	67	6
1932	14,154	.....	28	4	61	7
1933	9,757	.....	35	7	55	3
1934	36,242	.....	13	9	74	4
1935	12,712	.....	11	10	73	6
1936	28,562	.....	16	7	67	10
1937	17,567	.....	22	4	68	6
1938	21,462	.....	21	4	70	5
1939	24,357	.....	14	13	66	7
1940	13,809	.....	23	8	59	10
1941	24,876	.....	37	7	52	4
1942	21,085	.....	22	7	66	5
1943	13,412	.....	5	13	67	15
1944	13,083	.....	15	15	32	38
1945	9,899	.....	46	11	37	6
1946	12,511	.....	13	12	72	3
1947	10,849	.....	15	12	56	17
1948	13,181	.....	12	16	60	12
1949	9,268	.....	39	6	48	7
1950	27,286	.....	3	19	71	6
1951	24,405	.....	41	9	31	13
1952	29,492	304,500	28	19	46	4
1953	18,163	198,400	23	22	46	9
1954	10,285	101,600	35	20	40	5
1955	13,654	154,904	12	13	70	2

[1] To nearest hundred.

Table II.—Nass River Sockeyes, 1955, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals												Total
	3_1		4_1		4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
18	1	—	—	—	—	—	—	—	—	—	—	—	1
18¼	1	—	—	—	—	—	—	—	—	—	—	—	1
18½	—	—	—	—	—	—	—	—	—	—	—	—	—
18¾	—	—	—	—	—	—	—	—	—	—	—	—	—
19	—	—	—	—	—	1	—	—	—	—	—	—	1
19¼	—	—	—	—	—	—	—	—	—	—	—	—	—
19½	—	—	—	—	1	—	—	—	—	—	—	—	1
19¾	—	—	—	—	—	—	—	—	—	—	—	—	—
20	—	1	—	—	—	—	—	—	1	—	—	—	2
20¼	—	—	—	—	—	—	—	—	—	—	—	—	—
20½	—	—	—	—	1	5	—	—	1	3	—	—	10
20¾	—	—	—	—	—	3	—	—	—	3	—	—	6
21	1	1	—	—	—	4	1	—	2	4	—	—	13
21¼	—	—	—	—	1	2	1	—	1	9	—	—	14
21½	—	—	—	—	2	6	—	—	4	5	—	—	17
21¾	—	—	—	1	5	10	—	—	8	37	—	—	61
22	—	—	—	2	6	7	—	1	8	22	—	—	46
22¼	1	—	—	—	5	10	—	1	7	34	—	—	58
22½	—	—	—	—	6	7	—	2	9	21	—	—	45
22¾	—	—	—	2	13	12	—	—	24	78	—	—	129
23	—	—	1	—	2	5	1	1	10	40	—	—	61
23¼	—	—	—	—	6	1	—	1	24	40	—	1	72
23½	—	—	—	—	14	3	—	7	66	70	—	—	160
23¾	—	—	—	—	9	1	—	4	37	36	—	—	87
24	—	—	1	1	2	3	1	5	37	30	—	1	82
24¼	—	—	2	—	4	1	2	7	38	19	—	—	73
24½	—	—	—	—	4	—	2	12	51	39	—	—	108
24¾	—	—	1	—	—	—	5	7	25	13	—	—	51
25	—	—	—	—	1	—	6	9	27	12	1	—	56
25¼	—	—	—	—	—	2	8	9	22	16	1	2	60
25½	—	—	2	—	—	2	16	10	29	6	—	—	65
25¾	—	—	—	—	—	—	17	4	12	3	—	1	37
26	—	—	1	—	—	—	9	3	7	1	2	1	24
26¼	—	—	—	—	1	—	10	3	5	—	2	—	21
26½	—	—	1	—	—	—	17	1	10	1	—	1	31
26¾	—	—	—	1	—	—	10	—	3	—	2	—	16
27	—	—	—	—	—	—	5	—	—	1	—	—	6
27¼	—	—	—	—	—	—	6	1	1	—	1	—	9
27½	—	—	—	—	—	—	1	—	—	—	1	—	2
27¾	—	—	—	—	—	—	2	—	—	—	1	—	3
28	—	—	—	—	—	—	4	—	—	—	1	—	5
28¼	—	—	—	—	1	—	6	—	1	—	3	—	11
28½	—	—	—	—	—	—	—	—	—	—	—	—	—
28¾	—	—	—	—	—	—	—	—	—	—	—	—	—
29	—	—	—	—	—	—	—	—	—	—	—	—	—
29¼	—	—	—	—	—	—	—	—	2	—	—	—	2
29½	—	—	—	—	—	—	—	—	1	—	—	—	1
Totals	4	2	9	7	84	85	131	88	473	543	15	7	1,448
Average lengths	19.9	20.5	24.9	23.1	23.1	22.3	26.0	24.7	24.1	23.2	26.9	25.1	23.9

Table III.—Nass River Sockeyes, 1955, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals												Total
	3_1		4_1		4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
2½	1	—	—	—	—	—	—	—	—	—	—	—	1
2¾	1	—	—	—	—	—	—	—	—	—	—	—	1
3	—	—	—	—	—	1	—	—	—	—	—	—	1
3¼	—	1	—	—	—	—	—	—	—	—	—	—	1
3½	—	—	—	—	1	—	—	—	—	2	—	—	3
3¾	—	—	—	—	1	—	—	—	2	7	—	—	10
4	—	1	—	—	1	4	—	—	4	13	—	—	23
4¼	1	—	—	—	1	8	—	—	6	26	—	—	42
4½	—	—	—	2	2	17	1	—	8	57	—	—	87
4¾	—	—	—	—	5	10	—	—	9	44	—	—	68
5	—	—	—	2	11	15	—	1	34	83	—	—	146
5¼	1	—	1	1	6	7	1	1	21	38	—	—	77
5½	—	—	—	1	19	13	—	5	61	89	—	1	189
5¾	—	—	—	—	8	2	—	5	40	45	—	—	100
6	—	—	—	—	4	6	3	8	55	60	—	—	136
6¼	—	—	2	—	9	—	2	5	52	22	—	1	93
6½	—	—	1	1	9	—	5	13	50	24	—	—	103
6¾	—	—	1	—	5	—	5	13	24	14	—	—	62
7	—	—	—	—	1	2	11	16	38	7	2	2	79
7¼	—	—	1	—	1	—	8	4	21	5	3	1	44
7½	—	—	—	—	—	—	23	6	20	3	1	1	54
7¾	—	—	—	—	—	—	12	4	11	2	—	1	30
8	—	—	2	—	—	—	12	4	7	2	—	—	27
8¼	—	—	1	—	—	—	10	2	5	—	—	—	18
8½	—	—	—	—	—	—	8	—	2	—	1	—	11
8¾	—	—	—	—	—	—	11	—	2	—	4	—	17
9	—	—	—	—	—	—	9	—	1	—	2	—	12
9¼	—	—	—	—	—	—	2	—	—	—	—	—	2
9½	—	—	—	—	—	—	4	—	—	—	1	—	5
9¾	—	—	—	—	—	—	4	1	—	—	—	—	5
10	—	—	—	—	—	—	—	—	—	—	1	—	1
Totals	4	2	9	7	84	85	131	88	473	543	15	7	1,448
Average weights	3.7	3.7	6.9	5.2	5.6	4.9	7.8	6.8	6.1	5.4	8.3	6.9	6.0

Table IV.—Nass River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1955

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	24.5	23.7	26.3	25.2	26.1	25.3	27.7	26.4
1912–41 (conversion)	23.8	23.0	25.6	24.5	25.4	24.6	27.0	25.7
1942	23.9	23.2	26.1	24.9	24.9	24.3	26.9	26.0
1943	22.8	22.2	26.1	24.8	24.1	23.5	27.1	25.8
1944	23.5	22.7	25.7	24.6	24.8	23.8	26.8	25.8
1945	23.4	22.8	25.0	24.4	24.7	24.0	25.1	25.5
1946	23.4	22.4	26.3	24.9	24.9	23.9	28.1	26.0
1947	23.4	22.9	25.9	24.1	24.5	23.6	27.0	25.6
1948	23.3	22.6	26.2	25.3	25.0	24.1	27.7	26.7
1949	23.8	22.8	26.2	23.8	24.7	23.7	26.1	25.5
1950	23.6	23.1	26.0	24.7	24.5	23.7	26.7	25.6
1951	24.0	23.1	26.2	24.8	25.1	24.1	27.4	26.4
1952	23.9	23.1	26.8	25.3	24.8	23.9	27.6	26.3
1953	23.9	22.9	26.9	25.6	24.9	24.1	27.7	26.5
1954	24.1	23.1	26.5	25.3	25.3	24.5	27.7	26.0
1955	23.1	22.3	26.0	24.7	24.1	23.2	26.9	25.1

Table V.—Nass River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1955

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	6.0	5.4	7.3	6.4	6.9	6.2	8.0	7.0
1942	5.8	5.1	7.1	6.3	6.2	5.6	7.5	6.7
1943	5.2	4.7	7.6	6.4	5.9	5.3	7.9	6.9
1944	5.7	5.0	7.7	6.5	6.7	5.7	8.2	7.1
1945	5.7	5.3	7.0	6.4	6.5	5.9	7.2	7.1
1946	5.6	4.9	8.1	6.7	6.5	5.4	8.9	7.0
1947	5.8	5.3	7.7	6.2	6.3	5.6	8.1	6.9
1948	5.8	5.3	8.1	7.1	7.0	6.0	9.1	7.9
1949	5.9	5.1	7.9	5.8	6.5	5.4	7.7	6.8
1950	5.9	5.2	7.9	6.6	6.4	5.5	8.2	7.1
1951	6.0	5.2	7.9	6.6	6.7	5.7	8.8	7.6
1952	6.0	5.2	8.4	6.9	6.7	5.7	8.7	7.5
1953	6.2	5.4	8.3	7.2	6.6	5.8	9.0	7.9
1954	6.4	5.5	8.8	7.4	7.4	6.3	9.5	7.8
1955	5.6	4.9	7.8	6.8	6.1	5.4	8.3	6.9

Table VI.—Nass River Sockeyes, Percentages of Males and Females, 1915 to 1955

Year	4_2		5_2		5_3		6_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.		
1915–41 (average)	49	51	47	53	45	55	63	37	47	53
1942	42	58	48	52	44	56	70	30	45	55
1943	51	49	67	33	47	53	74	26	54	46
1944	53	47	45	55	39	61	60	40	50	50
1945	37	63	37	63	38	62	53	47	38	62
1946	62	38	59	41	45	55	75	25	50	50
1947	50	50	52	48	51	49	81	19	56	44
1948	45	55	54	46	52	48	66	34	53	47
1949	57	43	56	44	51	49	50	50	53	47
1950	41	59	42	58	43	57	58	42	44	56
1951	46	54	47	53	46	54	70	30	49	51
1952	49	51	56	44	49	51	59	41	50	50
1953	50	50	44	56	46	54	62	38	48	52
1954	42	58	44	56	44	56	45	55	43	57
1955	50	50	60	40	47	53	68	32	49	51

Table VII.—Skeena River Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Pack in Cases	Number of Sockeye[1]	Percentage of Individuals			
			4_2	5_2	5_3	6_3
1907	108,413	----	----	----	----	----
1908	139,846	----	----	----	----	----
1909	87,901	----	----	----	----	----
1910	187,246	----	----	----	----	----
1911	131,066	----	----	----	----	----
1912	92,498	----	57	43	----	----
1913	52,927	----	50	50	...	...
1914	130,166	----	25	75	...	...
1915	116,553	----	36	64	----	----
1916	60,923	----	34	38	13	18
1917	65,760	----	57	29	9	5
1918	123,322	----	51	34	9	6
1919	184,945	----	27	60	9	4
1920	90,869	----	15	71	6	8
1921	41,018	----	69	22	6	3
1922	96,277	----	70	16	12	2
1923	131,731	----	56	29	8	7
1924	144,747	----	23	69	7	1
1925	77,784	----	51	45	3	1
1926	82,360	----	62	26	9	3
1927	83,996	----	62	28	9	1
1928	34,559	----	51	39	7	3
1929	78,017	----	62	30	6	2
1930	132,372	----	39	52	8	1
1931	93,023	----	40	30	28	2
1932	59,916	----	44	37	7	12
1933	30,506	----	57	36	5	2
1934	54,558	----	58	34	7	1
1935	52,879	----	49	31	18	2
1936	81,973	----	67	20	11	2
1937	42,491	----	45	40	11	4
1938	47,257	----	64	15	16	5
1939	68,485	----	50	35	11	4
1940	116,507	----	80	15	4	1
1941	81,767	----	39	52	8	1
1942	34,544	----	36	54	7	3
1943	28,268	----	39	39	16	6
1944	68,197	----	37	52	7	4
1945	104,279	----	20	63	12	5
1946	52,928	----	13	70	8	9
1947	32,534	----	14	82	3	1
1948	101,267	----	80	13	6	1
1949	65,937	----	17	76	4	3
1950	47,479	----	21	72	4	3
1951	61,694	----	33	61	4	1
1952	114,775	1,294,500	66	26	3	5
1953	65,003	659,200	48	43	6	3
1954	60,817	571,900	33	54	10	2
1955	14,649	157,362	15	59	14	11

[1] To nearest hundred.

Table VIII.—Skeena River Sockeyes, 1955, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals																Total
	4_1		3_2		4_2		5_2		6_2		5_3		6_3		7_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
16			1														1
16¼			1														1
16½																	
16¾																	
17																	
17¼																	
17½																	
17¾																	
18																	
18¼																	
18½											1						1
18¾																	
19																	
19¼					2												2
19½																	
19¾					1												1
20					1						1			1			3
20¼											2						2
20½											1						1
20¾					7	1						2		1			11
21					1	4					2	1					8
21¼					3	2					1	2					8
21½					2	2		1			1	3	1				10
21¾					2	9					2	7					20
22					3	3		1				2		1			10
22¼					3	2		1			1	5					12
22½					1	3		1			1	2					8
22¾		1			5	6		7			4	4					27
23					3	2		8			5	2		1			21
23¼					1	2		6			1	2					12
23½					4	2	1	20			3	3	1	6			40
23¾					1		4	13			1	1	1				21
24					2		5	17			4		1	8			37
24¼					1		6	17			1	1	1	2			29
24½					4		15	30			3	1	4	4			61
24¾	1						11	11			2	2	2	5			34
25					2		7	22			2	1	3	1			38
25¼					1		11	14					2	1		1	30
25½							22	17	1		1		11	1			53
25¾							12	6			1		2				21
26							8	6			1	1	2				18
26¼					1		13	4					1				19
26½							15	3					1	1			20
26¾							4	1					1				6
27							2	1									3
27¼							6	1									7
27½													1				1
27¾							5										5
28																	
28¼							1										1
28½																	
28¾							1										1
29																	
29¼																	
Totals	1	1	2		51	38	149	208	1		42	42	35	33		1	604
Average lengths	24.7	22.7	16.0		22.5	22.0	25.5	24.5	25.5		23.0	22.5	25.2	24.0		25.3	23.7

Table IX.—Skeena River Sockeyes, 1955, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals																Total
	4_1		3_2		4_2		5_2		6_2		5_3		6_3		7_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
2			2														2
2¼																	
2½																	
2¾																	
3					2												2
3¼					2												2
3½					1						1						2
3¾						1					2						3
4					8	3					3	4					18
4¼					4	4					2	5					15
4½					5	9	3				2	5		1			25
4¾					3	4	5					6					18
5					6	7	10				1	7	1				32
5¼		1			1	4	2	12			7	1		1			29
5½					5	4	2	19			5	7		7			49
5¾					5	1	4	18			5	3		2			38
6					3	1	12	30			2	2	1	7			58
6¼							6	18			3	1	3	4			35
6½					3		13	17			6	1	5	5		1	51
6¾					2		13	15			1		5	1			37
7							19	18			2		7	2			48
7¼							5	10					1				16
7½	1				1		15	15					7	2			41
7¾							13	2	1				1	1			18
8							11	8					1				20
8¼							10	5									15
8½							5	1					1				7
8¾							2	1					1				4
9							7	1									8
9¼							5										5
9½																	
9¾							1						1				2
10							2										2
10¼							1										1
10½																	
10¾							1										1
Totals	1	1	2		51	38	149	208	1		42	42	35	33		1	604
Average weights	7.5	5.2	2.0		4.9	4.8	7.4	6.4	7.7		5.5	5.0	7.1	6.1		6.4	6.2

Table X.—Skeena River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1955

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	23.7	23.1	25.8	24.9	24.2	23.4	25.8	24.8
1912–41 (conversion)	23.0	22.4	25.1	24.2	23.5	22.7	25.1	24.1
1942	22.6	22.3	25.2	24.3	24.1	23.7	26.3	24.9
1943	21.9	21.9	25.1	23.9	23.3	22.6	25.8	24.7
1944	22.4	21.7	24.8	23.9	22.5	21.7	25.0	23.7
1945	22.6	22.3	24.9	24.1	23.3	22.6	25.0	24.3
1946	22.7	22.0	25.4	24.3	23.9	23.2	25.5	24.4
1947	22.3	22.0	25.1	23.8	23.0	22.4	26.3	25.8
1948	23.0	22.3	25.3	24.1	23.0	22.1	26.0	24.5
1949	22.5	22.2	25.3	24.5	23.2	22.3	24.8	23.9
1950	22.8	22.3	25.7	24.4	23.9	23.4	25.5	24.3
1951	22.7	22.6	25.9	24.8	23.6	22.9	26.0	24.6
1952	23.3	22.6	25.8	24.7	23.2	22.8	26.1	24.6
1953	23.2	22.8	26.2	25.0	23.6	22.9	26.0	25.5
1954	22.2	22.4	26.6	25.2	23.9	22.9	26.4	24.9
1955	22.5	22.1	25.6	24.5	23.0	22.6	25.2	24.0

Table XI.—Skeena River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1955

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	5.4	5.0	6.8	6.1	5.7	5.1	6.8	6.0
1942	4.9	4.7	6.7	6.0	5.8	5.4	7.2	6.6
1943	4.7	4.6	6.8	5.9	5.5	4.9	7.3	6.1
1944	5.1	4.6	7.0	6.1	5.3	4.6	7.1	5.8
1945	5.2	4.9	6.7	6.1	5.6	5.0	6.7	6.2
1946	4.7	4.2	6.9	5.8	5.8	5.1	7.0	6.1
1947	4.9	4.7	6.9	5.9	5.3	5.0	7.7	6.8
1948	5.5	4.9	7.3	6.1	5.4	4.7	7.7	6.4
1949	5.0	4.7	7.1	6.3	5.3	4.8	6.6	5.7
1950	4.8	4.3	7.2	5.9	5.8	5.1	6.8	5.6
1951	5.1	5.0	7.6	6.5	5.6	5.0	7.6	6.4
1952	5.6	5.0	7.5	6.4	5.6	5.0	7.4	6.0
1953	5.8	5.5	8.0	6.9	5.8	5.2	7.8	7.3
1954	4.9	4.9	8.8	7.2	6.2	5.2	8.6	7.2
1955	4.9	4.8	7.4	6.4	5.5	5.0	7.1	6.1

Table XII.—Skeena River Sockeyes, Percentages of Males and Females, 1915 to 1955

Year	4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.		
1915–41 (average)	48	52	43	57	46	54
1942	42	58	25	75	33	67
1943	50	50	31	69	43	57
1944	54	46	34	66	43	57
1945	41	59	35	65	38	62
1946	50	50	32	68	38	62
1947	50	50	29	71	33	67
1948	50	50	29	71	47	53
1949	54	46	30	70	36	64
1950	56	44	40	60	44	56
1951	41	59	37	63	39	61
1952	52	48	34	66	48	52
1953	40	60	34	66	39	61
1954	44	56	38	62	43	57
1955	57	43	42	58	47	53

Table XIII.—Rivers Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Pack in Cases	Number of Sockeye[1]	Percentage of Individuals			
			4_2	5_2	5_3	6_3
1907	87,874		—	—	—	—
1908	64,652		—	—	—	—
1909	89,027		—	—	—	—
1910	126,921		—	—	—	—
1911	88,763		—	—	—	—
1912	112,884		21	79	—	—
1913	61,745		80	20	—	—
1914	89,890		35	65	—	—
1915	130,350		13	87	—	—
1916	44,936		26	74	—	—
1917	61,195		39	61	—	—
1918	53,401		57	43	—	—
1919	56,258		46	54	—	—
1920	121,254		5	95	—	—
1921	46,300		49	51	—	—
1922	60,700		81	18	1	—
1923	107,174		74	24	2	—
1924	94,891		43	54	2	1
1925	159,554		23	77	—	—
1926	65,581		59	38	2	1
1927	64,461		81	16	3	—
1928	60,044		55	40	4	1
1929	70,260		77	18	3	2
1930	119,170		49	48	2	1
1931	76,428		53	44	2	1
1932	69,732		67	27	5	1
1933	83,507		44	55	1	—
1934	76,923		77	20	2	1
1935	135,038		57	41	1	1
1936	46,351		53	46	1	—
1937	84,832		60	37	3	—
1938	87,942		27	70	1	2
1939	54,143		67	32	1	—
1940	63,469		69	28	3	—
1941	93,378		59	40	1	—
1942	79,199		8	91	—	1
1943	47,602		8	91	—	1
1944	36,852		76	23	1	—
1945	89,735		57	41	2	—
1946	73,320		37	63	—	—
1947	140,087		3	97	—	—
1948	37,665		55	44	1	—
1949	39,495		84	14	1	—
1950	142,710		13	87	[2]	—
1951	102,565		38	60	1	1
1952	84,298	938,700	41	58	1	[2]
1953	132,925	1,522,300	73	26	1	[2]
1954	50,640	575,700	60	39	1	[2]
1955	50,702	584,128	45	54	[2]	1

[1] To nearest hundred.
[2] Age-class represented but less than 0.5 per cent.

Table XIV.—Rivers Inlet Sockeyes, 1955, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals								Total
	4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	
16	----	----	----	----	----	----	----	----	----
16¼	----	----	----	----	----	----	----	----	----
16½	1	----	----	----	----	----	----	----	1
16¾	----	----	----	----	----	----	----	----	----
17	----	----	----	----	----	----	----	----	----
17¼	----	----	----	----	----	----	----	----	----
17½	----	----	----	----	----	----	----	----	----
17¾	----	1	----	----	----	----	----	----	1
18	1	----	----	----	----	----	----	----	1
18¼	1	----	----	----	----	----	----	----	1
18½	----	1	----	----	----	----	----	----	1
18¾	5	2	----	----	----	----	----	----	7
19	8	3	----	----	----	----	----	----	11
19¼	8	2	----	1	----	----	----	----	11
19½	11	3	----	----	----	----	----	----	14
19¾	9	4	----	----	----	----	----	----	13
20	11	6	----	----	----	----	----	----	17
20¼	13	6	1	1	----	----	----	----	21
20½	10	7	----	----	----	----	----	----	17
20¾	12	8	----	----	----	----	----	----	20
21	12	12	----	----	----	1	----	----	25
21¼	8	7	----	----	----	----	----	----	15
21½	10	9	----	----	----	----	----	----	19
21¾	12	9	----	----	----	----	----	----	21
22	20	7	----	1	----	----	----	----	28
22¼	9	4	----	1	1	----	1	----	17
22½	6	5	1	4	----	----	----	----	16
22¾	7	1	----	9	----	1	----	----	18
23	9	----	3	9	----	----	----	----	21
23¼	5	----	----	2	----	----	----	----	7
23½	8	1	5	18	----	----	----	----	32
23¾	2	1	3	13	----	----	1	----	20
24	5	----	6	16	----	----	----	----	27
24¼	----	----	2	32	----	----	----	----	34
24½	1	----	8	30	----	----	----	----	39
24¾	1	1	7	25	----	----	----	----	34
25	----	----	10	27	----	----	----	----	37
25¼	1	----	5	21	----	----	----	----	27
25½	----	----	7	9	----	----	----	----	16
25¾	----	----	9	20	----	----	----	----	29
26	----	1	15	7	----	----	1	----	24
26¼	----	----	7	3	----	----	----	----	10
26½	----	----	4	2	----	----	----	----	6
26¾	----	----	9	4	----	----	----	----	13
27	----	----	6	----	----	----	----	----	6
27¼	----	----	3	----	----	----	----	----	3
27½	----	----	4	----	----	----	1	----	5
Totals	206	101	116	255	1	2	4	----	685
Average lengths	21.2	21.0	25.4	24.5	22.3	21.9	24.9	----	23.1

Table XV.—Rivers Inlet Sockeyes, 1955, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals								Total
	4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	
2	1	—	—	—	—	—	—	—	1
2¼	—	—	—	—	—	—	—	—	—
2½	—	2	—	—	—	—	—	—	2
2¾	2	1	—	—	—	—	—	—	3
3	8	9	—	1	—	—	—	—	18
3¼	13	2	—	—	—	—	—	—	15
3½	18	8	—	1	—	—	—	—	27
3¾	14	11	—	—	—	—	—	—	25
4	32	18	1	—	—	1	—	—	52
4¼	14	13	—	1	1	—	—	—	29
4½	24	13	—	4	—	—	—	—	41
4¾	16	8	—	3	—	1	—	—	28
5	15	8	3	8	—	—	—	—	34
5¼	14	3	3	5	—	—	2	—	27
5½	9	1	2	18	—	—	—	—	30
5¾	6	1	7	15	—	—	—	—	29
6	6	—	7	28	—	—	—	—	41
6¼	7	1	6	23	—	—	—	—	37
6½	4	—	8	40	—	—	—	—	52
6¾	2	—	2	18	—	—	—	—	22
7	1	1	6	30	—	—	—	—	38
7¼	—	—	12	12	—	—	—	—	24
7½	—	—	7	21	—	—	—	—	28
7¾	—	1	9	9	—	—	—	—	19
8	—	—	8	9	—	—	1	—	18
8¼	—	—	9	2	—	—	—	—	11
8½	—	—	10	3	—	—	—	—	13
8¾	—	—	3	3	—	—	—	—	6
9	—	—	4	—	—	—	—	—	4
9¼	—	—	4	—	—	—	—	—	4
9½	—	—	3	—	—	—	1	—	4
9¾	—	—	1	1	—	—	—	—	2
10	—	—	—	—	—	—	—	—	—
10¼	—	—	—	—	—	—	—	—	—
10½	—	—	1	—	—	—	—	—	1
10¾	—	—	—	—	—	—	—	—	—
Totals	206	101	116	255	1	2	4	—	685
Average weights	4.5	4.2	7.4	6.5	4.3	4.4	7.0	—	5.8

Table XVI.—Rivers Inlet Sockeyes, Average Lengths in Inches of the 4_2 and 5_2 Groups, 1912 to 1955

Year	4_2		5_2	
	M.	F.	M.	F.
1912–41	22.4	22.4	25.4	24.7
1912–41 (conversion)	21.6	21.6	24.6	23.9
1942	21.9	21.3	25.0	23.8
1943	20.5	21.1	24.3	23.7
1944	21.1	21.0	23.5	23.3
1945	20.9	21.2	24.2	23.9
1946	20.6	21.1	25.1	24.1
1947	20.6	20.7	24.0	23.5
1948	21.4	21.3	25.2	24.2
1949	20.9	21.4	23.8	22.8
1950	21.1	20.8	25.2	24.2
1951	21.9	21.9	25.8	24.8
1952	21.5	21.5	26.0	25.0
1953	21.6	21.8	26.5	25.3
1954	22.0	21.6	26.1	25.1
1955	21.2	21.0	25.4	24.5

Table XVII.—Rivers Inlet Sockeyes, Average Weights in Pounds of the 4_2 and 5_2 Groups, 1914 to 1955

Year	4_2		5_2	
	M.	F.	M.	F.
1914–41	4.9	4.8	7.0	6.5
1942	5.1	4.6	7.2	6.4
1943	4.1	4.4	6.8	6.3
1944	4.6	4.4	6.2	6.0
1945	4.3	4.4	6.6	6.4
1946	3.9	3.9	7.2	6.2
1947	4.1	3.9	6.4	5.9
1948	4.7	4.6	7.9	7.0
1949	4.4	4.3	5.9	5.9
1950	4.2	3.9	7.5	6.4
1951	5.2	5.0	8.6	7.4
1952	4.9	4.7	8.7	7.4
1953	4.7	4.7	8.8	7.6
1954	5.2	4.8	8.9	7.6
1955	4.5	4.2	7.4	6.5

Table XVIII.—Rivers Inlet Sockeyes, Percentages of Males and Females, 1915 to 1955

Year	4_1		4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.		
1915–41 (average)	....	....	63	37	34	66	50	50
1942	....	....	61	39	35	65	38	62
1943	....	....	62	38	34	66	36	64
1944	....	....	67	33	33	67	59	41
1945	....	....	70	30	39	61	57	43
1946	....	....	79	21	37	63	53	47
1947	....	....	72	28	35	65	36	64
1948	....	....	50	50	38	62	45	55
1949	36	64	70	30	22	78	63	37
1950	50	50	75	25	36	64	41	59
1951	....	....	66	34	30	70	44	56
1952	....	....	58	42	34	66	44	56
1953	....	....	55	45	33	67	49	51
1954	50	50	67	33	29	71	52	48
1955	....	....	67	33	31	69	48	52

Table XIX.—Smith Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Pack in Cases	Number of Sockeye[1]	Percentage of Individuals				
			4_1	4_2	5_2	6_2	5_3
1925	33,764						
1926	17,921						
1927	22,682						
1928	33,442						
1929	9,683						
1930	32,057						
1931	12,867						
1932	25,488						
1933	37,369						
1934	14,607						
1935	31,648						
1936	12,788						
1937	25,258						
1938	33,894						
1939	17,833						
1940	25,947						
1941	21,495						
1942	15,939						
1943	15,010						
1944	3,165						
1945	15,014			50	50		
1946	14,318			11	89		
1947	36,800			5	95		
1948	10,456			7	90	3	
1949	13,189		2	92	5		(2)
1950	42,435			17	83		(2)
1951	49,473			22	77	(2)	(2)
1952	34,834	342,200		8	91	(2)	1
1953	29,947	367,100		89	10	1	(2)
1954	18,937	190,800	1	61	38		1
1955	28,864	325,478		42	58		(2)

[1] To nearest hundred.

[2] This age-class was represented by less than 0.5 per cent of the number of fish in the sample.

Table XX.—Smith Inlet Sockeyes, 1955, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals						Total
	4_2		5_2		5_3		
	M.	F.	M.	F.	M.	F.	
18	1	—	—	—	—	—	1
18¼	—	—	—	—	—	—	—
18½	—	—	—	—	—	—	—
18¾	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—
19¼	—	—	—	—	—	—	—
19½	1	—	—	—	—	—	1
19¾	1	—	—	—	—	—	1
20	2	1	—	—	—	—	3
20¼	4	1	—	—	—	—	5
20½	10	7	—	—	—	—	17
20¾	14	6	—	—	—	—	20
21	27	8	—	—	—	—	35
21¼	23	5	—	—	—	—	28
21½	25	14	—	—	—	—	39
21¾	22	10	1	—	—	—	33
22	32	9	—	1	—	—	42
22¼	18	5	—	1	—	1	25
22½	26	5	—	1	—	—	32
22¾	12	3	—	2	—	—	17
23	11	1	—	7	—	—	19
23¼	6	—	—	9	—	—	15
23½	4	1	3	9	—	—	17
23¾	—	—	3	24	—	—	27
24	3	—	8	28	—	—	39
24¼	—	—	13	27	—	—	40
24½	—	—	11	35	—	—	46
24¾	1	—	12	31	—	—	44
25	—	—	13	36	—	—	49
25¼	—	—	22	20	—	—	42
25½	—	—	16	23	—	—	39
25¾	—	—	20	7	—	—	27
26	1	—	16	11	—	—	28
26¼	—	—	8	1	—	—	9
26½	—	—	8	2	—	—	10
26¾	1	—	3	1	—	—	5
27	—	—	4	—	—	—	4
27¼	—	—	2	—	—	—	2
27½	—	—	1	—	—	—	1
27¾	—	—	—	—	—	—	—
Totals	245	76	164	276	—	1	762
Average lengths	21.8	21.6	25.3	24.6	—	22.3	23.5

Table XXI.—Smith Inlet Sockeyes, 1955, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals						Total
	4_2		5_2		5_3		
	M.	F.	M.	F.	M.	F.	
2	—	—	—	—	—	—	—
2¼	—	—	—	—	—	—	—
2½	1	—	—	—	—	—	1
2¾	—	—	—	—	—	—	—
3	—	—	—	—	—	—	—
3¼	—	—	—	—	—	—	—
3½	1	—	—	—	—	—	1
3¾	4	1	—	—	—	—	5
4	16	9	—	—	—	—	25
4¼	23	10	—	—	—	—	33
4½	34	20	1	1	—	—	56
4¾	26	6	—	1	—	1	34
5	44	13	—	1	—	—	58
5¼	30	8	—	3	—	—	41
5½	33	7	—	11	—	—	51
5¾	12	2	2	8	—	—	24
6	11	—	4	26	—	—	41
6¼	5	—	8	17	—	—	30
6½	4	—	16	41	—	—	61
6¾	—	—	9	25	—	—	34
7	—	—	10	48	—	—	58
7¼	—	—	13	26	—	—	39
7½	—	—	23	33	—	—	56
7¾	—	—	11	13	—	—	24
8	1	—	25	16	—	—	42
8¼	—	—	9	—	—	—	9
8½	—	—	14	3	—	—	17
8¾	—	—	12	2	—	—	14
9	—	—	5	1	—	—	6
9¼	—	—	2	—	—	—	2
9½	—	—	—	—	—	—	—
9¾	—	—	—	—	—	—	—
Totals	245	76	164	276	—	1	762
Average weights	5.0	4.7	7.5	6.9	—	4.7	6.2

Table XXII.—Smith Inlet Sockeyes, Average Lengths in Inches of Age-groups, 1945 to 1955

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945	—	—	22.2	22.0	25.1	24.4	—	—	—	—
1946	—	—	21.3	22.7	24.7	24.0	—	—	—	—
1947	—	—	23.2	23.4	25.2	24.3	—	—	—	—
1948	—	—	21.9	21.7	25.0	24.3	26.7	25.0	—	—
1949	25.4	23.5	21.4	21.7	24.6	24.3	—	25.5	—	—
1950	—	—	21.6	21.7	24.8	24.0	—	—	20.5	—
1951	—	—	22.8	22.0	25.6	24.8	—	25.1	23.4	—
1952	—	—	21.8	22.4	25.7	24.9	—	25.1	22.9	23.1
1953	—	24.3	22.9	22.3	25.9	25.2	—	—	22.8	23.3
1954	26.3	25.0	22.3	21.9	25.7	24.9	—	—	23.0	23.5
1955	—	—	21.8	21.6	25.3	24.6	—	—	—	22.3

Table XXIII.—Smith Inlet Sockeyes, Average Weights in Pounds of Age-groups, 1945 to 1955

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945	—	—	4.9	4.7	7.1	6.5	—	—	—	—
1946	—	—	4.6	5.8	7.3	6.6	—	—	—	—
1947	—	—	5.7	5.5	6.9	6.0	—	—	—	—
1948	—	—	5.1	5.4	7.6	6.9	10.3	7.5	—	—
1949	7.9	6.1	5.0	5.1	7.2	6.7	—	7.3	—	—
1950	—	—	4.9	5.0	7.4	6.6	—	—	4.0	—
1951	—	—	6.0	5.2	8.2	7.3	—	7.2	6.4	—
1952	—	—	4.8	5.2	8.0	7.1	—	7.3	5.7	5.4
1953	—	5.9	5.9	5.3	8.2	7.6	—	—	5.7	5.8
1954	8.0	7.1	5.2	4.7	7.9	7.0	—	—	5.8	5.8
1955	—	—	5.0	4.7	7.5	6.9	—	—	—	4.8

Table XXIV.—Smith Inlet Sockeyes, Percentages of Males and Females, 1945 to 1955

Year	4_1		4_2		5_2		6_2		5_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.		
1945	—	—	73	27	49	51	—	—	—	—	61	39
1946	—	—	76	24	37	63	—	—	—	—	41	59
1947	—	—	38	62	47	53	—	—	—	—	46	54
1948	—	—	79	21	42	58	11	89	—	—	43	57
1949	36	64	80	20	40	60	—	100	—	—	77	23
1950	—	—	86	14	42	58	—	—	100	—	49	51
1951	—	—	72	28	41	59	—	100	100	—	48	52
1952	—	—	57	43	38	62	—	100	63	37	40	60
1953	—	100	60	40	36	64	—	—	71	29	58	42
1954	25	75	70	30	25	75	—	—	25	75	52	48
1955	—	—	76	24	37	63	—	—	—	100	54	46

Table XXV.—Skeena Test-fishing Sockeyes, 1955, Grouped by Age, Length, and by Their Early History

Length in Inches	Number of Individuals						Total
	3_2	4_2	5_2	4_3	5_3	6_3	
13¾	1						1
14							
14¼	1						1
14½	4						4
14¾							
15	13			1			14
15¼	13						13
15½							
15¾	15						15
16							
16¼	14						14
16½	5		1				6
16¾							
17	2						2
17¼	2	1					3
17½							
17¾	2	1					3
18		1			1		2
18¼							
18½		5	1				6
18¾							
19		8				1	9
19¼		3	1				4
19½							
19¾		11			1		12
20		13					13
20¼							
20½		18	2				20
20¾		28	1		3	2	34
21							
21¼		33	7		12		52
21½							
21¾		27	2		15		44
22		34	8		8	1	51
22¼		1			1		2
22½		26	16		9		51
22¾		19	31		7	1	58
23							
23¼		16	35		4	4	59
23½		11	53		5	8	77
23¾			1				1
24		5	44		2	14	65
24¼			2				2
24½		2	65		1	12	80
24¾		2	72		2	10	86
25			1				1
25¼		3	65		3	10	81
25½		3	51		2	10	66
25¾							
26		2	50		1	5	58
26¼			25				25
26½			1		1	7	9
26¾			21			2	23
27			1				1
27¼		1	12		1	1	15
27½			7				7
27¾						1	1
28		1					1
28¼							
28½							
28¾							
29			1				1
29¼							
29½			1				1
Totals	72	275	577	2	79	89	1,094
Average lengths	15.7	21.7	24.6	15.8	22.5	24.7	23.1
Percentage	6.2	25.1	52.7	0.2	7.2	8.1	

Table XXVI.—Commercially Caught Skeena River Sockeyes, 1955, Grouped by Age, Length, and by Their Early History

Length in Inches	Number of Individuals								Total
	4_1	3_2	4_2	5_2	6_2	5_3	6_3	7_4	
15									
15¼									
15½									
15¾									
16		1							1
16¼		1							1
16½									
16¾									
17									
17¼									
17½									
17¾									
18									
18¼									
18½						1			1
18¾									
19									
19¼			2						2
19½									
19¾			1						1
20			1			1	1		3
20¼						2			2
20½						1			1
20¾			8			2	1		11
21			5			3			8
21¼			5			3			8
21½			4	1		4	1		10
21¾			11			9			20
22			6	1		2	1		10
22¼			5	1		6			12
22½			4	1		3			8
22¾	1		11	7		8			27
23			5	8		7	1		21
23¼			3	6		3			12
23½			6	21		6	7		40
23¾			1	17		2	1		21
24			2	22		4	9		37
24¼			1	23		2	3		29
24½			4	45		4	8		61
24¾	1			22		4	7		34
25			2	29		3	4		38
25¼			1	25			3	1	30
25½				39	1	1	12		53
25¾				18		1	2		21
26				14		2	2		18
26¼			1	17			1		19
26½				18			2		20
26¾				5			1		6
27				3					3
27¼				7					7
27½							1		1
27¾				5					5
28									
28¼				1					1
28½									
28¾				1					1
29									
29¼									
Totals	2	2	89	357	1	84	68	1	604
Average lengths	23.8	16.1	22.3	24.9	25.5	22.8	24.6	25.3	24.2
Percentage	0.3	0.3	14.7	59.1	0.2	13.9	11.3	0.2	

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Use of Antibiotics for the Preservation of Fish and Sea Foods

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and H. L. A. TARR, Ph.D.

Reported upon here is the successful use of ice containing chlortetracycline (CTC) in preserving salt water fish while in transit to markets.

Sea foods are peculiarly susceptible to spoilage occasioned by putrefactive microorganisms, and there are probably comparatively few individuals in civilized communities who have not had their olfactory senses shocked by odors from stale fish or shellfish. Indeed, sea foods usually spoil much more rapidly than meats obtained from warm-blooded animals when stored at ordinary refrigerator temperatures, and the reason for this is almost certainly because marine products are invariably contaminated with psychrophilic bacteria. These organisms not only multiply quite rapidly at refrigerator temperatures, but spoil fish about twice as fast at 37° F as at 30° F.

In spite of these facts those of us who are familiar with fish-handling methods are aware of the apparent lack of interest by pure food authorities in establishing sanitary standards for fish-handling establishments and for setting up quality standards for fish itself. There are probably several reasons for this. In the fishing industry we have large- and small-scale, widely scattered operations, and many of these are seasonal in nature. This results in employment of transient and seasonal labor, and it is certain that the vast majority of plants are seriously lacking in general sanitary facilities. It is safe to say that there are few, if any, fish plants which could approach the sanitary conditions prevailing in a modern dairy plant, and that from this point of view the fishing industry is at least two decades behind the dairy industry. Sanitary conditions in modern meat plants are also undoubtedly much better than those found in the fishing industry.

Why has the handling and processing of sea foods not been more closely covered by government inspection measures? There is little doubt that the main reason is because fish has not been very frequently implicated in human food poisoning. Oysters and certain other shellfish, which are often eaten uncooked, are usually subject to quite stringent regulations since there have been in the past quite frequent and serious outbreaks of enteric diseases as a result of their consumption. If fish had been more frequently implicated in occasioning human disease, there is little doubt that it would have been subjected to stricter control. Though fish has occasioned all the well known types of food poisoning, outbreaks have been

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comparatively infrequent,[12] and strict regulations covering handling of this commodity are rarely found.

The foregoing remarks may not seem particularly germane to the present subject, but they indicate the technologically rather backward condition of the fishing industry. However, it is in this industry that our research efforts are made, and it is obvious that one of our important problems is the improvement in bacteriological quality of fish. Though proper vessel and fish plant sanitation are obviously highly desirable for production of high-quality fish, it is quite possible to prepare fish of excellent bacteriological quality in quite primitive premises. In other words, the maintenance of high sanitary standards on fishing vessels and at shore plants does not necessarily insure good quality fish, though from an aesthetic standpoint alone such conditions are highly desirable. It is the actual handling and treatment of the fish themselves which is of prime importance in determining their keeping quality.

The muscle and organ tissues of healthy fish are, so far as is known, usually free, or practically free, from bacteria and it is the external slime and digestive tracts of feeding fish which contain the bacteria responsible for spoilage. It is not easy to control growth of these normally psychrophilic organisms once fish are killed, though prompt freezing and proper frozen storage prevent bacterial growth. However, for fish which are not to be frozen the only practicable storage technics are to hold them in crushed ice where the temperature of the fish usually varies between about 0° and 3° C, depending on the efficiency of the icing method used, or to store them at −1° C in refrigerated sea water.[13, 18, 19] Temperatures below −1° C cannot be used since fish muscle tissue will freeze slowly under these conditions.

Even with the best icing methods or storage in chilled sea water, bacterial spoilage occurs, the rate depending on the initial bacterial contamination and species of fish. Though ideally such spoilage may be avoided by short storage periods and great care in icing procedures, there exist many conditions in the fishing industry where such ideal procedures are not followed. Thus in British cod fisheries we are told that fish have often been held two weeks or more in ice, and Pacific halibut are also often of this post-mortem age when landed. There are other fisheries where fish are not eviscerated and are poorly iced or not iced at all. Some of these conditions should be improved, but there is always the argument that the economic situation is such that it is impossible to do this.

At our station the campaign against bacterial spoilage of fish has been waged for three decades, and it seems that at long last we have obtained a reasonable measure of success in our efforts. Since the results of our earlier work have been reviewed,[17] only the recent work we have carried out—and are still actively pursuing—on use of antibiotics will be covered. Reviews and original articles dealing with antibiotics in fish or shellfish preservation have been published from other laboratories.[4, 6, 7, 10, 23]

Our work with antibiotics actually started in 1943 when penicillic acid was prepared and tested as a possible preservative for fish with poor success.[16] Later penicillin and streptomycin were examined with similar disappointing results.[20] In the spring of 1950 a number of the newer antibiotics were studied and the findings were much more encouraging since Aureomycin, Terramycin and Chloromycetin all gave quite significant preservation in comparatively low concentration.[21] Further experiments convinced us that, of some 14 antibiotics examined, Aureomycin (chlortetracycline, CTC) was the most effective [22] and it is with this antibiotic

that all our applied studies have been conducted.[3, 8, 13, 18, 19] Some of our more recent studies on CTC and other antibiotics and preservative agents will now be discussed.

Effect of Several New Antibiotics and Furan Derivatives on Growth of Bacteria in Fish Flesh—The following substances were studied: (1) Antibiotics: Aureomycin (Lederle Laboratories), Amphomycin, Etamycin, Bryamycin (Bristol Laboratories, Inc.); and (2) Furan derivatives: Furoxone, Furadantin, Nitrofurazone (Furacin), and N. F. 56 (N-5-nitro-2 furfurylidene-1-aminoguanidine sulphate) (Eaton Laboratories, Inc.). The technic was similar to that employed in previous studies with ground flesh,[22] 5 ml of a solution containing the necessary concentration of the compound being added to 95 gm of ground flesh of strictly fresh fish con-

Table 1—Effect of Various Antibiotics and Furan Derivatives on Growth of Bacteria in Minced Lingcod Muscle at 0° and 4° C

Compound	Concentration μg/gm	Bacteria x 10^6/gm After Days at 1° C 6	1° C 8	5° C * 6	5° C * 6
None		27.0	> 600.0	600.0	130.0
Aureomycin (CTC)	2.5	1.3	0.5	7.0	19.0
	5.0	0.5	0.8	4.8	
Amphomycin	5.0			450.0	
	10.0			700.0	
Bryamycin	5.0				98.0
	10.0	92.0	340.0		
	20.0	19.0	470.0		
Etamycin	5.0		910.0		
	10.0		380.0		
Furoxone	2.5				32.0
Furadantin	2.5				85.0
Nitrofurazone	2.5				114.0
	10.0	37.0	> 900.0		
	25.0	57.0	310.0		
	50.0	19.0	900.0		
NF-56	2.5				63.0
	25.0	157.0	837.0		
	50.0	76.0	367.0		
CTC + Bryamycin	5.0				
	10.0	2.7	8.0		
CTC + Bryamycin	2.5				
	5.0	4.0	1.0		
NF-56	25.0		> 900.0		
+ Bryamycin	10.0				
Nitrofurazone	25.0				
+ Bryamycin	10.0	18.0	400.0		

* Results of two separate experiments.

tained in sterilized capped glass jars. The samples were stored at either 1° or 5° C. Where possible aqueous solutions of the compounds were used, but with those which were relatively insoluble in water either formamide or propylene glycol were employed as solvents. Thus Bryamycin was dissolved in formamide and all the furan derivatives in propylene glycol and appropriate water dilutions of these solutions were used. It was found that these solvents alone in the final concentration used exerted no important bacteriostatic effect. In all experiments bacterial counts were made by a direct counting procedure.[15]

The results of several experiments carried out with lingcod (Ophiodon elongatus), spring salmon (Oncorhynchus tschawytscha), and halibut (Hippoglossus stenolepis) are given in Tables 1 and 2. In all experiments CTC caused a marked and prolonged suppression of bacterial growth in concentrations of from 1 to 5 μg/gm. The antibiotics Amphomycin, Bryamycin, and Etamycin in considerably higher concentrations (5–25 μg/gm) exerted no significant bacteriostatic effect, and Bryamycin combined with CTC appeared to make the latter less effective. None of the furan derivatives studied exerted a significant bacteriostatic effect. It is apparent that so far CTC is the most effective substance found for flesh food preservation.

Commercial Trials with CTC-Containing Ice—During the past three years, with collaboration and encouragement of our fishing industry, we have conducted experiments of increasing magnitude to assess the commercial value of CTC-ice for icing fish [8, 13, 19] and on the inhibition of bacterial spoilage of whales [5] and oysters [2] with CTC solutions. This spring it was arranged that

Table 2—Effect of Various Antibiotics and Furan Derivatives on Growth of Bacteria in Minced Salmon and Halibut Muscle

Compound	Concentration μg/gm	Bacteria x 10^6/gm After 8 Days at 1° C Salmon	Halibut
None	0	900.0	573.0
Aureomycin (CTC)	1.0		1.1
	5.0	2.0	0.6
Amphomycin	10.0		260.0
	25.0		222.0
Bryamycin	5.0	267.0	
	10.0	279.0	210.0
	25.0		200.0
Etamycin	10.0		337.0
	25.0		148.0
NF-56	10.0	> 1,000.0	414.0
	25.0	> 900.0	144.0
Nitrofurazone	10.0		259.0
	25.0		63.0
Furoxone	10.0		207.0
	25.0		67.0
Furadantin	10.0		247.0
	25.0		130.0

several large vessels operating from a local company would take alternately ordinary ice and CTC-containing ice. These vessels use otter trawls and bring in gray cod (Gadus macrocephalus), and various species of "flounders" and "ocean perch" (Sebastodes species). Since the price paid for these fish is comparatively poor, the fish are not eviscerated and the icing technic is not always very efficient. Though in past trials with eviscerated well iced salmon [8] we found 1 μg/gm of CTC in ice particularly effective, it was decided to use 2.5 μg/gm in these tests in view of the somewhat less efficient icing procedures. Block ice containing "Acronize BI" (American Cyanamid's concentrate which contains carrageen, calcium acetate, and 16 per cent chlortetracycline) in half the suggested concentration was prepared. In trials of this sort the problem of sampling is extremely difficult for the vessels usually landed from 50,000 to 80,000 lb of fish. To add to the difficulty, after initial reluctance to use a new type of ice, two vessel captains found that it was preventing spoilage and the consequent loss which often occurred. Toward the conclusion of the trials it became impossible to obtain fish iced with ordinary ice.

The arbitrary sampling method involved securing at random six to 10 fish, the post-mortem age being recorded by the vessel captain. These were iced in their respective ices and brought to the laboratory and filleted under clean conditions without prior evisceration. The unskinned fillets were placed in polyethylene bags and stored at 10° C in order to accelerate bacterial spoilage.[15, 19] At stated intervals some of the fillets were skinned under clean conditions and others used directly. They were ground with three volumes of water in a blender equipped with sharp steel blades so that the skin was macerated. Direct bacterial counts were made as usual.

The results of this experiment are given in Table 3. It will be observed that the results are somewhat irregular, and this can only be expected from an experiment of this type where adequate sampling was hardly possible. However, for similar total storage treatment (vessel storage in ice plus accelerated storage at 10° C) fish iced with CTC-ice had much lower bacterial counts. This experiment indicates the difficulty that is experienced in sampling a large load of fish.

Effect of Addition of CTC to Fish Flesh on Development of Clostridium botulinum (Type E) and an Enterotoxigenic Strain of Staphylococcus aureus—Outbreaks of food poisoning resulting from fish consumption are comparatively rare, but have occurred from time to time,[12] and consequently it seemed important to determine the effect of CTC added to fish flesh upon the development of bacteria causing two types of food poisoning. These experiments were purposely carried out with fresh lingcod flesh obtained under very clean conditions, but which was slightly contaminated with the natural spoilage flora.

Minced flesh was used in all experiments, 48 gm being placed in sterilized screw-capped jars and 2 ml of water or of CTC-hydrochloride solution added to give a final concentration of 2 μg/gm. Vegetative cells of C. botulinum Type E were obtained by growing the organism in Bacto-thioglycollate broth for 24 hours at 37° C anaerobically.[11] Spores of the same organism were obtained by growing the organism under similar conditions for 48 hours. The spore-containing cultures were heated 20 minutes at 80° C to destroy vegetative cells, higher temperatures being avoided because of the comparative heat lability of spores of this type of C. botulinum. S. aureus was cultivated for 24 hours on Bacto-nutrient broth at 37° C. The vegetative cells or spore cultures of these organisms were highly diluted

Table 3—Effect of Aureomycin on the Keeping Quality of Gray Cod and Sole

	Days Stored in Ice on Vessel	Accelerated Storage Time at 10° C (hr.)	Bacteria x 10^6/gm Gray Cod Fillets Unskinned	Gray Cod Fillets Skinned	Sole Fillets Unskinned	Sole Fillets Skinned
CTC ice	5	72	0.4	0.8	0.8	0.5
		96	1.7	11.0	18.0	12.0
		120	2.0	15.0	6.0	18.0
	6	24	0	0.2		
		48	0	0.2		
		72	0	0.2		
	8	48		0		0
		96		7.0		21.0
		160		22.0		11.0
	10	24				1.0
		48				6.0
		72				10.0
	12 *	24		0.5		1.0
	13	24				0.4
		48			3.7	2.0
		72			15.0	3.7
Ordinary ice	3	72		15.0		
		96		9.0		
	4	24	0.5	0.2	0	0
		48	2.2	0.7	0.7	0
		72	12.0	6.3	2.0	4.0
	5	68	24.0	15.0	44.0	59.0
		93		59.0		162.0
	12 * †	24		9.5		6.0

* Includes subsequent six days storage on shore.
† A portion of this catch was of poor quality and was reduced for fish meal.

with sterile saline to the desired cell concentration which was established by microscopic count. Three separate experiments were carried out as follows:

1. C. botulinum spores in a concentration calculated to give approximately 1,040 per gm of flesh were added to lingcod flesh, with and without added CTC. The number of spores present initially and after five days at 10° C in these samples was determined by heating the flesh at 80° C for 20 minutes followed by the usual serial dilution method, 1 ml of appropriately diluted fish muscle being added to 9 ml of thioglycollate broth. The tubes were incubated one week anaerobically at 37° C and growth determined visually. The results (Table 4) indicate that spores of C. botulinum do not develop appreciably in fish muscle at 10° C and that CTC is without effect under these conditions. The fish had not been stored under strictly anaerobic conditions and this probably accounts at least in part for the lack of spore development, since

Table 4—Effect of CTC on Spores of C. botulinum Type E in Fish Flesh

		Growth Observed After One Week at 37° in Thioglycollate Broth Containing the Following Calculated Numbers of Spores											
		1,040	520	260	130	65	32	16	8	4	2	1	0
Initial values	No CTC	++++	++++	++++	+++	+++	+++	++	+	−	−	−	−
	Plus CTC	++++	++++	++++	+++	+++	+++	++	+	−	−	−	−
Three days at 10° C.	No CTC	++++	++++	++++	+++	+++	+++	++	++	−	−	−	−
	Plus CTC	++++	++++	++++	+++	+++	++	++	+	−	−	−	−

trials showed that spores of this organism do develop slowly under anaerobic conditions in thioglycollate medium at this temperature.

2. An experiment identical with the above was carried out except that vegetative cells of C. botulinum were used instead of spores. In this experiment an extra step was introduced in which the serial dilutions from the fish samples were inoculated into thioglycollate broth without heating. These tubes were incubated one week at 37° C to encourage growth and sporulation and the medium heated at 80° C for 20 minutes to destroy vegetative cells. Transfers were then made to fresh broth tubes and the incubation repeated. The results (Table 5) show that though no apparent increase of the organisms occurred under the experimental conditions, there was a marked reduction of vegetative cells in the stored fish containing CTC, but not in that which did not contain CTC.

3. About one million Staphylococcus aureus cells per gm were introduced into samples of minced lingcod flesh, with and without added CTC, and the samples stored five days at 10° C. In this experiment it will be seen that the initial content of introduced staphylococcus organisms was about 14 times that of the natural flora. The results of the experiment (Table 6) show that the bacterial counts in the fish with added CTC had only increased to about the same extent after five days in both inoculated and uninoculated samples. In absence of CTC the increase was greater in the sample with added S. aureus. This indicates that, under conditions where S. aureus will multiply in fish flesh, CTC strongly retards its development.

Summary

During the past year there has been an important development in the controversial subject of the use of antibiotics

Table 5—Effect of CTC on Vegetative Cells of C. botulinum Type E in Fish Flesh

		Growth Observed After One Week at 37° in Thioglycollate Broth Containing the Following Calculated Numbers of Vegetative Cells											
		1,100	550	275	138	69	35	18	9	4	2	1	0
Initial values	No CTC	++++	++++	++++	+++	+++	+++	++	+	+	−	−	−
	Plus CTC	++++	++++	++++	+++	+++	+++	++	+	+	−	−	−
Three days at 10° C.	No CTC	++++	++++	++++	+++	+++	+++	++	++	+	−	−	−
	Plus CTC	+++	+++	++	+	−	−	−	−	−	−	−	−

Table 6—Effect of CTC on Growth of S. aureus in Fish Flesh

Samples			Bacteria ($\times 10^6$/gm)
Initial counts		uninoculated fish	0.08
		S. aureus added	1.1
Counts after 5 days at 10° C	No CTC added	uninoculated fish	4.7
		inoculated with S. aureus	11.3
	CTC added	uninoculated fish	1.7
		inoculated with S. aureus	2.6

in foods. The U. S. Food and Drug Administration has permitted treatment of eviscerated poultry with CTC,[1] and the American Medical Association has indicated the harmlessness of such treatment.[9] Research concerned with possible industrial applications of CTC has proceeded actively in several laboratories. Subjects such as addition of the antibiotic to flake ice,[19] its distribution in block ice,[3, 8, 24] and other modes of application, such as by use in dipping solutions,[6, 17, 19, 23] or in refrigerated sea water,[13, 19] have been studied. During the past year this laboratory has carried out extensive commercial trials with block ice containing CTC and the results have been very favorable, though really adequate sampling of large vessel loads of fish has not proved practicable. The results obtained in one such trial have been recorded.

The search for antibiotics or other substances which could prove valuable in preventing microbiological spoilage of fish or fish waste products is continuing, and the results of trials with several new antibiotics and furan derivatives are presented. It has been argued that suppression of the natural bacterial flora of fish by introduction of CTC might create favorable conditions for growth of food poisoning organisms should these be present, but these studies indicate that this is unlikely to occur with C. botulinum Type E and with enterotoxigenic staphylococci. There is undoubtedly room for further work along these lines, particularly with shellfish. In conclusion, it is important to refer to the question of CTC residues in fish flesh. All available published information suggests that these would either be absent or present in negligible amounts in cooked fish.[7, 10, 14, 19] The results of our recent studies on this problem were presented last month at the antibiotic meeting in Washington and it is hoped that they will eventually be published.

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